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Research Article

Redescription of *Gastrophysa atrocyanea* (Motschulsky) and *G. polygoni* (Linnaeus) (Insecta: Coleoptera: Chrysomelidae: Chrysomelinae), with Notes on Their Biology

Chi-Feng Lee[1,*]

Abstract

Lee, C. F. 2022. Redescription of *Gastrophysa atrocyanea* (Motschulsky) and *G. polygoni* (Linnaeus) (Insecta: Coleoptera: Chrysomelidae: Chrysomelinae), with notes on their biology. J. Taiwan Agric. Res. 71(4):281–292.

Gastrophysa atrocyanea (Motschulsky, 1860) is a Chrysomelinae species that appears only during spring, with only one record reported from Taiwan. More specimens were collected from Kinmen islands. This species was redescribed, based on morphological characteristics, including the penis, gonocoxae, spermatheca, and abdominal ventrite VIII in females. Another widespread species, *G. polygoni* (Linnaeus), was compared to test the diagnostic value of these characters. Detailed biological information is provided for *G. atrocyanea*, including larval and adult feeding behaviors, host plants, and life cycle. *G. polygoni elongata* Jolivet 1951 is proposed as a junior synonym of the nominate subspecies.

Key words: Leaf beetles, Taxonomy, Polygonaceae, *Rumex nipponicus*, *Rumex crispus*.

INTRODUCTION

Gastrophysa Chevrolat, 1836 is a small chrysomeline genus containing seven species in the Palaearctic region (Kippenberg 2010). It can be recognized from other chrysomeline genera by combination of the following characters: anterior coxal cavities open posteriorly, simple tarsal claws, interior margin of elytral epipleuron lacking setae, and elytral punctures randomly arranged. The genus is also characterized by the angular tibial apex (Fig. 13) bearing a slender, flattened process along the interior margin (Fig. 14).

Gastrophysa atrocyanea (Motschulsky, 1860) was first recorded from Taiwan by Jolivet (1951) when he revised this genus. No additional specimens were mentioned in Chûjô's revision of Taiwanese Chrysomelinae (Chûjô 1958). Chang (2017) recorded this species from Liehyu Island (烈嶼), one of the Kinmen Islands. A series of adults were collected from leaves of *Rumex nipponicus* on Kinmen Island by Mr. Wei-Ting Liu in April 2008. He is a member of the Taiwan Chrysomelid Research Team, which is composed of ten members and has been inventorying all leaf beetles in Taiwan since 2005. I found substantial populations of this species on *Rumex nipponicus* during early March 2022. I here redescribe this species and describe diagnostic characters which were missed by previous studies. The diagnostic value of other genitalic characters were evaluated by comparisons with those of another widespread congener, *G. polygoni* (Linnaeus). Biological information is noted specially for populations in the Kinmen Islands.

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MATERIALS AND METHODS

For rearing studies, larvae were placed in a small glass containers (diameter 142 mm × height 50 mm) with cuttings from their host plants. When mature larvae began to search for pupation sites, they were transferred to a smaller plastic containers (diameter 90 mm × height 57 mm) filled with moist soil, the amount about 80% of container volume.

For delimiting variability of diagnostic characters, at least one pair from each locality was examined. Length was measured from the anterior margin of the eye to the elytral apex, and width at the greatest width of the elytra. All voucher specimens were deposited at the Applied Zoology Division, Taiwan Agricultural Research Institute (TARI), Taichung, Taiwan.

RESULTS

Gastrophysa atrocyanea Motschulsky, 1860

Gastrophysa atrocyanea Motschulsky, 1860: 222 (Russia: East Siberia); Baly 1874: 175 (Japan, Northern China); Marseul 1878: 142 (redescription; East Siberia); Lewis 1879: 28 (catalogue; Japan); Jacoby 1885: 754 (catalogue; Japan); Marseul 1888: 371 (key, redescription); Jolivet 1951: 14 (revision); Chûjô 1958: 19 (redescription of Taiwanese species); Chûjô and Kimoto 1961: 152 (catalogue; host plants); Gressitt and Kimoto 1963: 340 (China: Fujian, Gansu, Hunan, Liaoning); Kimoto 1964: 270 (Japan: Kyushu, Honshu); Kippenberg 2010: 393 (China: Hebei, Jiangxi; Russia: Far East); Yang *et al*. 2015: 29 (China: Heilongjiang, Inner Mongolia, Shaanxi, Qinghai, Shanghai, Anhui, Yunnan).

Gastroidea atrocyanea: Horald 1874: 3403 (catalogue); Schönfeldt 1887: 181 (catalogue; Japan); Chen 1934: 52 (redescription; China: Beijing, Hubei, Jiangsu, Sichuan, Zhejiang; Vietnam); Chen 1936: 164 (redescription); Chûjô 1940: 80 (Japan: Shikoku); Chûjô 1941: 72 (Korea).

Gastroidea tonkinea Achard, 1923: 134 (Vietnam). Synonymized with *G. atrocyanea* by Chen (1934).

Specimens examined. CHINA. Heilongjiang: 1 ex., Yu-chuan, Harbin (= Ping-Kiang Prov.), 25-28.VI.1938, leg. M. Nikitin; Hubei: 1 ex., Mts. Wu-schan; Zhejiang: 1 ex., Hangchow (杭州), 19.III.1933, leg. C. C. Tao; **JAPAN.** Honshu: 1 ex., Ikeda, Osaka, 18.V.1932, leg. K. Iwata; 1 ex., same but with “10.VI.1932”; 1 ex., Yokohama, 15.V.1880, leg. G. Lewis; Kyushu: 2 exs., Mt. Korasan, Chikugo, 7.IV.1934, leg. K. Yamauchi; 1 ex., Mozi, 10.VI.1940, leg. N. Mori; Shikoku: 2 exs., Kochi-ken, 19.V.1935, leg. I. Okubo; **SOUTH KOREA**: 1 ex., Kankyo Nando, Hokusei gun, 3.VIII.1937, leg. M. Yamada; 1 ex., Keikidô, Suigen (= Suwon), 3.VI.1933, leg. D. Okamoto; **TAIWAN.** Kinmen: 34 exs., Jinhu (金湖), 30.IV.2008, leg. W.-T. Liu; 3 exs., Jincheng (金城), 9.III.2022, leg. C.-F. Lee; 9 exs., Lieyu (烈嶼), 16.IV.2015, leg. Y.-J. Chang; 5 exs., same but with “19.IV.2015”; 15 exs., same but with “24.IV.2016”.

Redescription. Length 5.5–6.1 mm, width 2.7–3.5 mm. General color (Figs. 1–3) dark metallic purple, except apex of abdominal ventrite V yellow. Antennomeres II–VI filiform in males, VII–X moniliform, XI lanceolate (Fig. 7), ratios of lengths of antennomeres I to XI 1.0 : 0.7 : 0.7 : 0.8 : 0.6 : 0.6 : 0.6 : 0.6 : 0.6 : 0.6 : 1.1; ratios of length to width from antennomeres I to XI 2.0 : 1.9 : 2.3 : 2.2 : 1.8 : 1.4 : 1.2 : 1.1 : 1.1 : 1.1 : 2.1; similar in females (Fig. 8), ratios of lengths of antennomeres I to XI 1.0 : 0.6 : 0.8 : 0.7 : 0.5 : 0.5 : 0.5 : 0.6 : 0.5 : 0.5 : 0.9; ratios of length to width from antennomeres I to XI 2.2 : 1.9 : 2.5 : 2.3 : 1.7 : 1.3 : 1.2 : 1.3 : 1.1 : 1.2 : 2.1. Pronotum 1.5–1.6 times wider than long; disc with dense, coarse punctures, lateral margins slightly rounded, widest above middle; apical margins slightly concave and basal margin slightly convex at middle. Elytra 1.4–1.5 times longer than wide; disc with dense, coarse punctures; parallel-sided, apices rounded. Aedeagus (Fig. 9, 10) extremely broad, about 2.8 times longer than wide; parallel-sided; subapically narrowed, apex widely rounded; moderately curved in lateral view; tectum well sclerotized and short, apical margin slightly depressed at middle; endophallic sclerites composed of three parts: (1) a pair of lateral sclerites connected to each oth-

er, with one transverse sclerite near apex, short and longitudinal; (2) one medial sclerite, basally broader; and (3) one curved sclerite ventrally concealed at middle. Gonocoxae (Fig. 15) longitudinal and separated; each gonocoxa basally narrowed and apex widely rounded, with dense short setae at apical area. Ventrite VIII (Fig. 11) with apex weakly sclerotized, dense short setae along apical areas; apical margin with deep furrow at middle. Spermathecal receptaculum (Fig. 12) slender, not separated from pump; pump long and curved; sclerotized spermathecal duct extremely long, with base wide.

Variation. Adults of Japanese populations are much yellow on the abdomen, including entire ventrite V and apex of ventrite IV.

Diagnosis. Adults of *Gastrophysa atrocyanea* can be recognized by their color pattern: entire body dark metallic blue (Figs. 1–3) [yellow dorsum, black scutellum and suture of elytra in *G. mannerheimi* (Stål); greenish-blue body, yellowish-brown pronotum, bases of antennae and legs in *G. polyoni* (Linnaeus) (Figs. 4–6); metallic green body, dark green legs and antennae in *G. viridula* (DeGeer)]. In genitalic characters, *G. atrocyanea* differs from *G. polygoni* by lacking a longitudinal groove at the apex of the aedeagus, shorter tectum, and longitudinal lateral sclerites of the internal sac (Figs. 9, 10) [short longitudinal groove at apex of aedeagus, longer tectum, and curved lateral sclerites of internal sac in *G. polygoni* (Figs. 26, 27)]; basally narrow gonocoxae (Fig. 15) [wider basal half of gonocoxae in *G. polygoni* (Fig. 30)]; and deep furrow at middle of apical margin of abdominal ventrite VIII in females (Fig. 11) [shallow furrow at middle of apical margin of abdominal ventrite VIII in females of *G. polygoni* (Fig. 28)].

Host plants. Leaves of *Polygonum aviculare*, *Persicaria maculosa* (= *Polygonum persicaria*), *Rumex acetosa*, *R. conglomeratus*, *R. japonicus*, *R. longifolius*, *R. madaio* (Polygonaceae), and *Stellaria aquatica* (Caryophyllaceae) (Chûjô & Kimoto 1961). Naito *et al.* (1979) tested the host specificity of this species and found that *Rumex obtusifolius* was the most favorable food plant. In addition, certain species of *Polygonum*, such as *P. persicaria* and *P. filiforme* also proved favorable. Xiaoshui (1991) also tested the host specificity, and found that both larvae and adults fed on *R. japonicus* and *R. acetosa* while the former was favored. Larvae also fed on two *Polygonum* species, *P. hydropiper* and *P. perfoliatum*. But adults were not found on these two species. In Kinmen Island populations, larvae and adults fed on leaves of *R. nipponicus*, but adults were only found feeding on leaves of *R. crispus*.

Biological notes. This species is univoltine. In Japan, overwintered adults begin to oviposit in early spring. Larvae are most abundant in late April and early May. Newly emerged adults feed for some 10 d before they enter into the soil in middle June to rest until the following spring (Miyazaki 1979). In China, adults were observed copulating and laying eggs in early March. Each female laid 725–1156 eggs. The eggs were deposited on the undersurfaces of leaves in batches of about 34. Incubation lasted 9−10 d. Young larvae were gregarious on leaves. The larvae passed through three instars for a total of 16−20 d. Mature larvae left the plant and tunneled into moist soil to pupate underground. Adults emerged after 7−9 d. In the field they consumed some older leaves of remaining *R. japonicus* for a short period of time, and then disappeared from the host until the following year (Xiaoshui 1991).

In Taiwan, *Rumex nipponicus* was observed seriously defoliated caused by *Gastrophysa atrocyanea* (Figs. 16) on March 9, 2022, at Jincheng (金城) township, Kinmen islands. Eggs (Fig. 18), larvae (Fig. 19) and adults (Fig. 21) were found on leaves. Larvae grazed on undersides of leaves (Fig. 17). All adults went into resting period in a few days. Mature larvae (Fig. 19) burrowed into the soil for pupation. The pupal stage (Fig. 20) lasted 4 d only at room temperature (18℃). Newly emerged adults fed on plant leaves for 3 d then entered their resting phase. April 13, 2022, the plant of *Rumex nipponicus* were found almost dead when I visited again after one month later. No individuals of *G. atrocyanea* were present on plants. During that visit, I found some adults feeding on leaves of *R. crispus* (Figs. 22, 23) at Jinhu (金湖) township. It appeared

that only the adults were feeding based on the shape of the feeding damage (Figs. 23).

Distribution. China, Japan, Korea, Russia, Taiwan, Vietnam.

Gastrophysa polygoni (Linnaeus, 1758)

Chrysomela polygoni Linnaeus, 1758: 370 (Europe).

Gastrophysa polygoni: Chevrolat 1836: 405; Jolivet 1951: 10 (revision).

Gastroeidea polygoni: Hope 1840: 164; Chen 1936: 164 (China: Beijing); Chûjô 1941: 73 (Korea); Chûjô 1942: 59 (China: Guandong).

Chrysomela ruficollis Fabricius, 1775: 820 (England). Regarded as an abnormal form of *G. polygoni* by Jolivet (1951).

Chrysomela obtusa Müller, 1776: 82. Regarded as an abnormal form of *G. polygoni* by Jolivet (1951).

Chrysomela caeruleipennis Say, 1825: 296 (United States). Synonymized with *G. polygoni* by Harris (1842).

Phaedon rubripes Philippi and Philippi, 1864: 390 (Chile, mislabeled). Synonymized with *G. polygoni* by Askevold (1991).

Gastrophysa polygoni elongata Jolivet, 1951: 13 (China). syn. nov.

Specimens examined. AUSTRIA. 2 exs., Neusidel. S., leg. Schuster; **CHINA.** Guandong. 4 exs., Ryosuiji, 23.VII.1936, leg. M. Hanano; 1 ex., same but with "26.VII.1939"; **FRANCE.** 7 exs., Foret de Fougere, Ille et Vilaine, 30.VII.1937, leg. C. Bourveau; **GERMANY.** 1 ex., Siegmündung, 3.VII.19??; **NORTH KOREA.** 1 ex., Naiso, Mt. Myoko, Heian-Hokudo, 29.VII.1937, leg. T. Kusanagi; 1 ex., Gonei, Mt. Myoko, Heian-Hokudo, 31.VII.1937, leg. T. Kusanagi; 1 ex., same locality, 31.VII.937, leg. M. Yamada; 1 ex., Kokai, Koaki-Gun, Heian-Hokudo, 18.VIII.1936, leg. M. Yamada; **ROMANIA.** 1 ex., Siebenbürgen, leg. Schuster.

Redescription. Length 4.7–5.4 mm, width 2.6–3.0 mm. General color (Figs. 4–6) metallic green, but prothorax and legs yellow, except tarsi blackish-brown, antennae black but four or five basal antennomeres yellowish-brown, apex of abdominal ventrite V yellow. Antennomeres II–VI filiform in males, VII–X moniliform, XI lanceolate (Fig. 24), ratios of lengths of antennomeres I to XI 1.0 : 0.6 : 0.7 : 0.6 : 0.6 : 0.6 : 0.7 : 0.7 : 0.7 : 0.6 : 1.1; ratios of length to width from antennomeres I to XI 2.6 : 1.8 : 2.1 : 1.9 : 1.6 : 1.5 : 1.6 : 1.6 : 1.5 : 1.3 : 2.3; similar in females (Fig. 25), ratios of lengths of antennomeres I to XI 1.0 : 0.6 : 0.7 : 0.6 : 0.6 : 0.6 : 0.6 : 0.6 : 0.6 : 0.6 : 1.0; ratios of length to width from antennomeres I to XI 2.4 : 1.7 : 2.1 : 1.9 : 1.9 : 1.5 : 1.5 : 1.5 : 1.5 : 1.3 : 2.3. Pronotum 1.7 times wider than long; disc with dense, coarse punctures, lateral margins slightly rounded, widest above middle; apical margins slightly concave and basal margin slightly convex at middle. Elytra 1.3–1.4 times longer than wide; disc with dense, coarse punctures; parallel-sided, apices rounded. Aedeagus (Fig. 26, 27) extremely wide, about 2.8 times longer than wide; parallel-sided; subapically narrowed, apex widely rounded; middle of apical margin with short longitudinal groove; moderately curved in lateral view; tectum well sclerotized and long, apical margin moderately depressed at middle; endophallic sclerites composed of three parts: (1) a pair of lateral elongate, strongly curved sclerites; (2) one medial sclerite basally widened; and (3) one curved sclerite concealed at middle. Gonocoxae (Fig. 30) longitudinal and separated, each gonocoxa widened at basal half and apex widely rounded, with dense, short setae apically. Ventrite VIII (Fig. 28) with apex weakly sclerotized, dense, short setae along apical areas; apical margin with shallow furrow at middle. Spermathecal receptaculum (Fig. 29) slender, not separated from pump; pump long and curved; sclerotized spermathecal duct extremely long, with base wide.

Diagnosis. Adults of *Gastrophysa polygoni* can be recognized by their color pattern: greenish-blue body, yellowish-brown pronotum and bases of antennae and legs (Figs. 4–6) [dark metallic blue body with yellowish-brown abdominal ventrite V in *G. atrocyanea* (Figs. 1–3); yellow dorsum, black scutellum and suture of elytra in *G. mannerheimi* (Stål); metallic green body, dark green legs and antennae in *G. viridula* (DeGeer)].

Genitalic characters of *G. polygoni* differ from those of *G. atrocyanea* by presence of short longitudinal groove near apex of aedeagus, with longer tectum, and curved lateral sclerites of internal sac (Figs. 26, 27) [lacking longitudinal groove at apex of aedeagus, with shorter tectum, and longitudinal lateral sclerites of internal sac in *G. polygoni* (Figs. 9, 10)]; widened basal half of gonocoxae (Fig. 30) [basally narrow gonocoxae in *G. polygoni* (Fig. 15)]; and shallow furrow at middle of apical margin of abdominal ventrite VIII in females (Fig. 28) [deep furrow at middle of apical margin of abdominal ventrite V in females of *G. polygoni* (Fig. 11)].

Notes. *Gastrophysa polygoni elongata* was described by Jolivet (1951) based on Chinese specimens. It is regarded as a junior synonym of the nominate subspecies since differences between both subspecies were not found based on material examined during this study.

Host plants. The true host plants of *G. polygoni* are limited to the plant family Polygonaceae, mainly in the genera *Polygonum*, *Fallopia*, and *Rumex*, although a considerable number of unrelated, secondary, or incidental hosts have been reported (LeSage & Majka 2009). In Europe, the preferred host is *Polygonum aviculare* and to a lesser extent *Fallopia convolvulus* (Sotherton 1982).

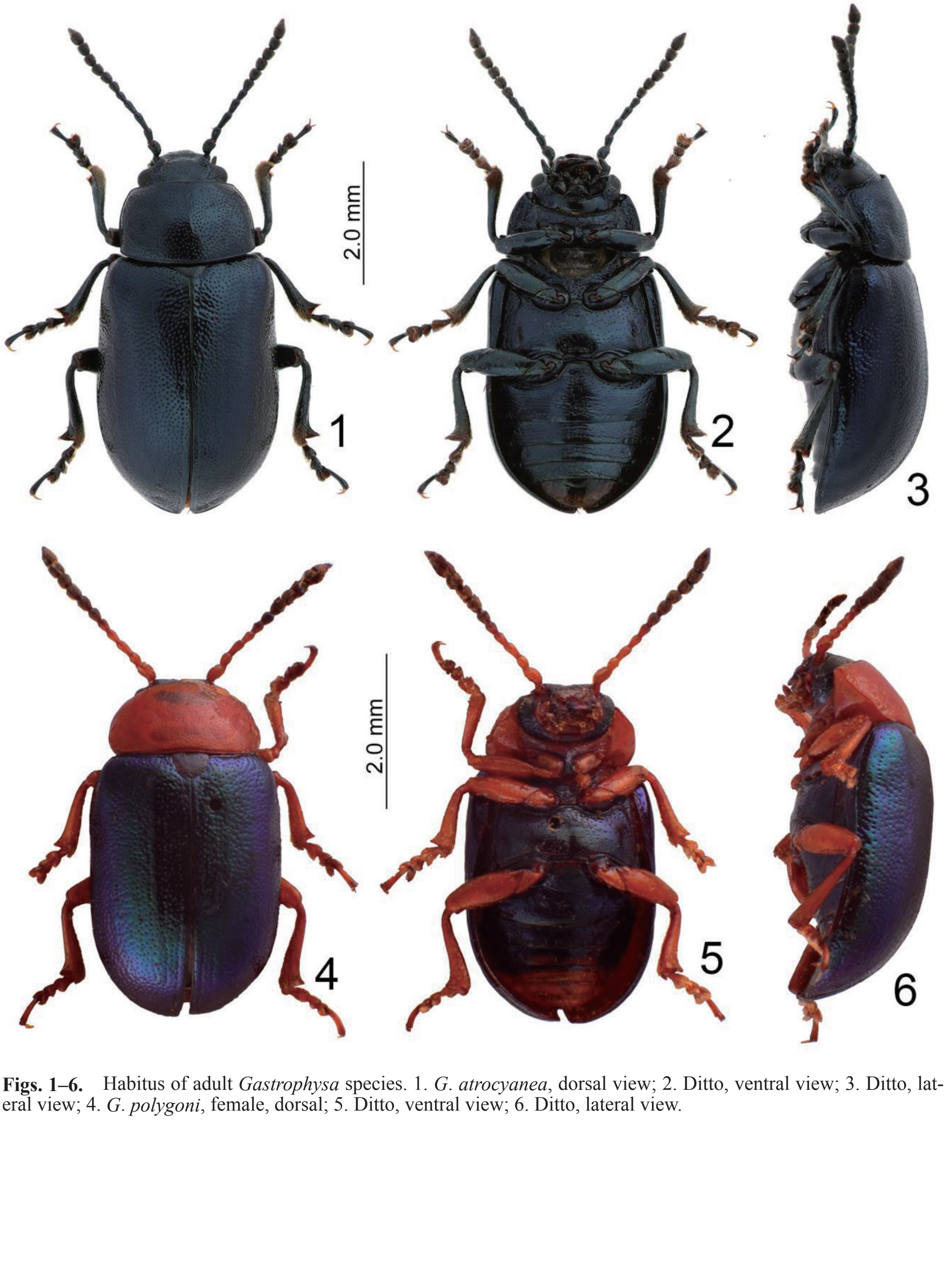
Biologcal notes. Overwintered adults leave their winter shelters in late April or early May in southern England. Adults mate a few days after emergence. They feed by eating margins of leaves. No noticeable weight increase is observed in the male, but females become noticeably larger when gravid. Egg laying begins after a pre-oviposition period of 6–11 d. The oviposition period lasts about 44 d, begins in early May, peaking at the end of the month. The eggs are enveloped with a glutinous matter, and laid in batches on the underside of leaves. The number of eggs laid in a batch ranges from 17 to 98. Fecundity measured in the field varied from 835 to 1,016 eggs per female in the first generation, to 587 to 1,028 eggs in the second. The oviposition period lasts 43–45 d in the first generation, 19–33 d in the second. A partial third generation may occur in some years. The number of generations is not fixed and these develop continuously one after the other over the year. First instars feed on the egg chorion before feeding on the host plant. First instars fenestrate the leaves, remaining on those on which they hatch, whereas second and third instars chew holes through the leaves and tend to move from plant to plant. When fully developed, they enter the soil where they pupate in an earthen cell. A complete life cycle was obtained in 19−29 d. Adults of the first generation emerged from the soil in late June and early July in southern England. The total duration of the development of the first generation varied from 35 to 69 d, that of the second generation from 31 to 53 d (LeSage & Majka 2009).

Distribution. The species occurs throughout the Palearctic region from Europe east to Siberia, China, and Korea. It was introduced into North America during the nineteenth century (LeSage & Majka 2009).

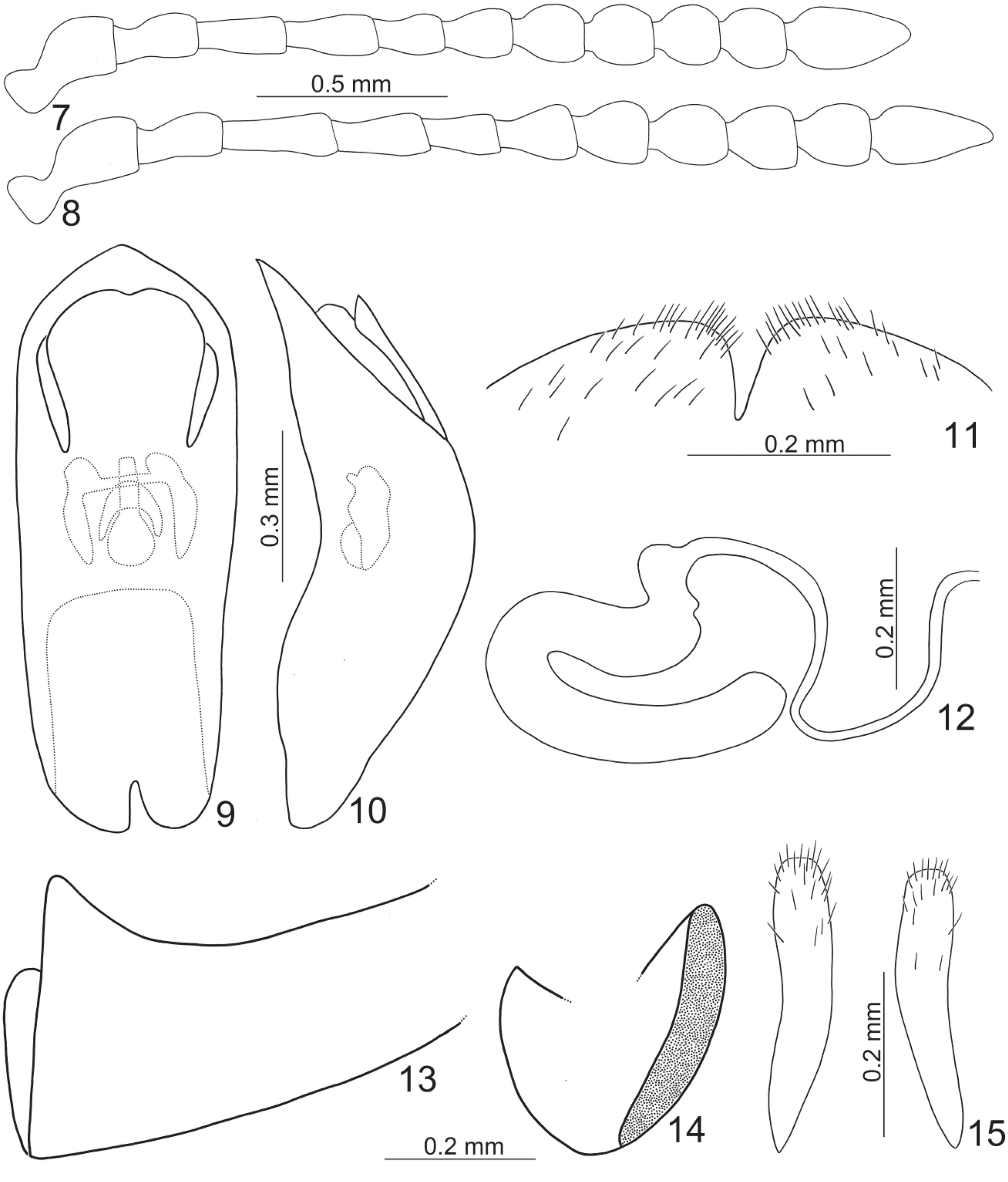
CONCLUSION

Although most species of *Gastrophysa* can be identified based on color patterns, other morphological characters were studied and illustrated before. Jolivet (1951) illustrated the aedeagus of each species of the genus, but they are less diagnostic because only the outlines were provided. Actually, shapes of the endophallic sclerites are diagnostic based on study of *G. atrocyanea* and *G. polygoni*. Such structures were omitted by Jolivet (1951) and other studies (such as Yang *et al*. 2015). In the current study, antennae of both sexes and spermatheca are not used for species identification but are useful for generic diagnosis. In addition to aedeagus, the abdominal ventrite VIII in females and gonocoxae are proved to be diagnostic for species identities.

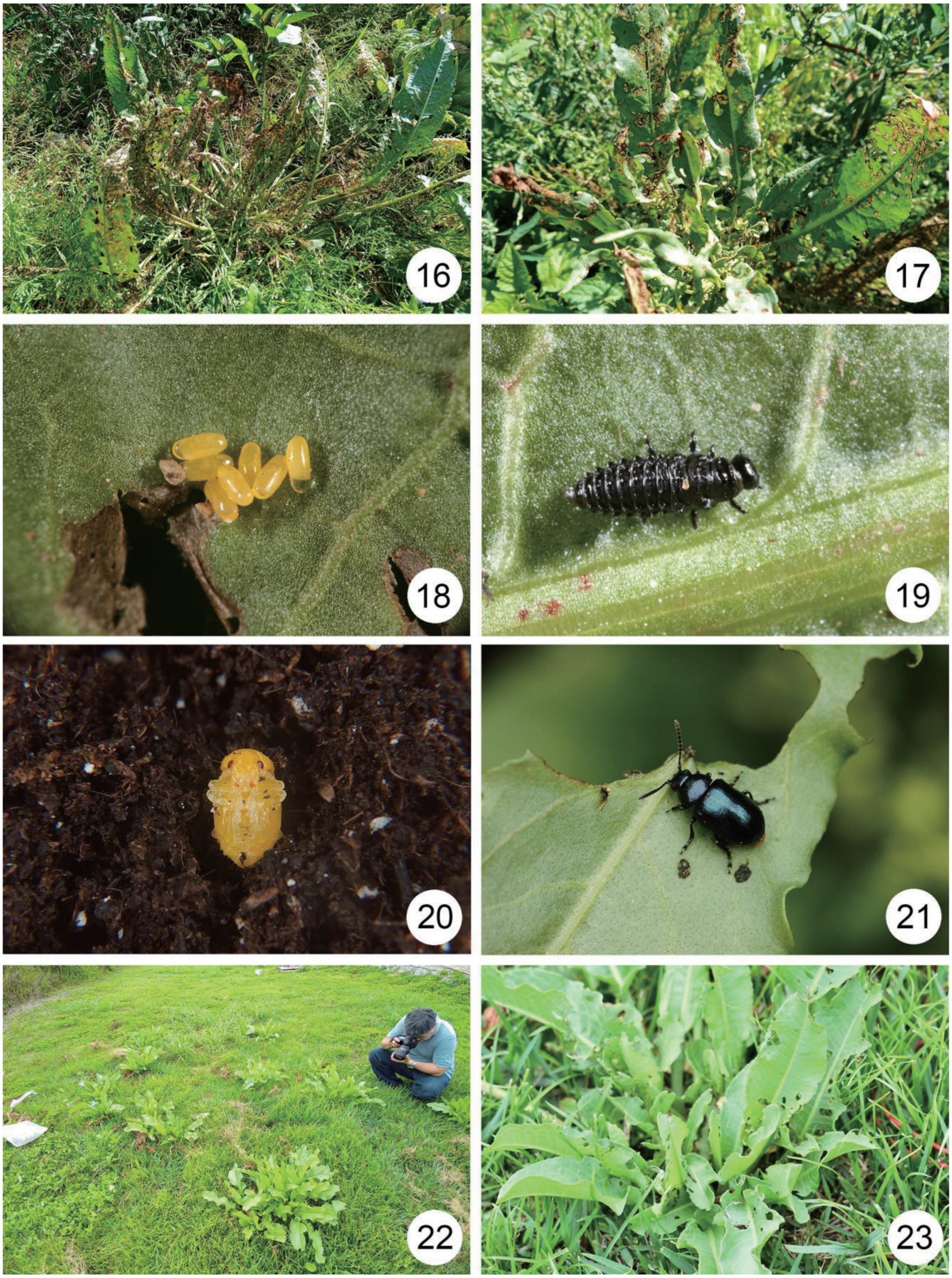
Based on field observations in Kinmen islands during 2022, *Rumex nipponicus* is the true host plant for *Gastrophysa atrocyanea*. Both larvae and adults were observed feeding on the leaves. The overwintered adults probably left from their winter shelters as early as mid-February since some newly emerged adults as well as



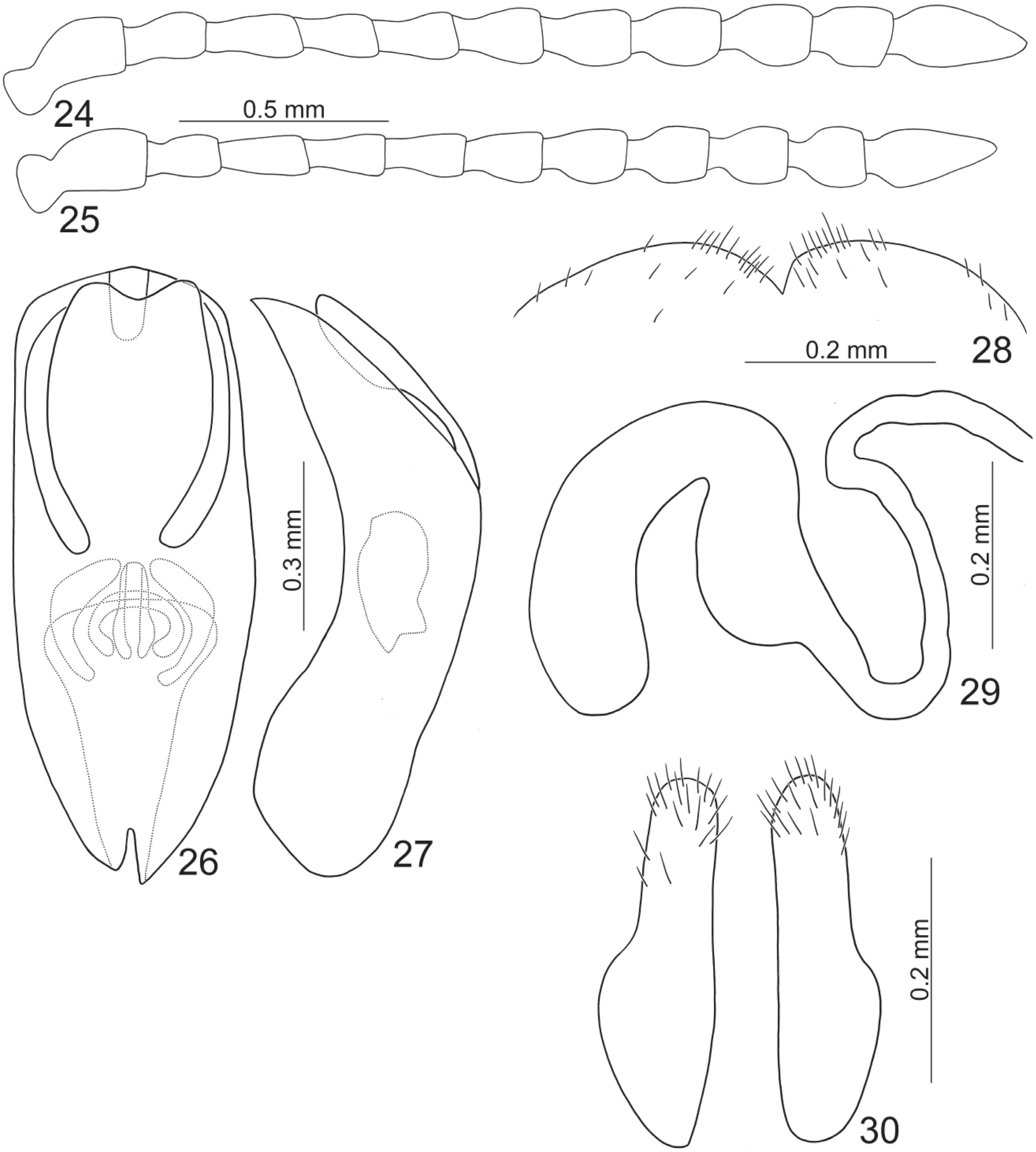
Figs. 1–6. Habitus of adult *Gastrophysa* species. 1. *G. atrocyanea*, dorsal view; 2. Ditto, ventral view; 3. Ditto, lateral view; 4. *G. polygoni*, female, dorsal; 5. Ditto, ventral view; 6. Ditto, lateral view.



Figs. 7–15. Diagnostic characters of *Gastrophysa atrocyanea*. 7. Antenna, male; 8. Antenna, female; 9. Aedeagus, dorsal view; 10. Aedeagus, lateral view; 11. Ventrite VIII, female; 12. Spermatheca; 13. Apical half of tibia of hind leg, lateral view; 14. Apex of tibia of hind leg, front view; 15. Gonocoxae.



Figs. 16–23. Field photographs of *Gastrophysa atrocyanea*. 16. *Rumex nipponicus* seriously defoliated caused by larvae of *G. atrocyanea* in March 9, 2022, at Jincheng (金城) township; 17. At same locality and date, damage caused by larvae on leaves of *R. nipponicus*; 18. Egg batch; 19. Third-instar larva; 20. Pupa; 21. Adult; 22. Population of *R. crispus* on April 13, 2022, at Jinchu (金湖) township; 23. Damage on leaves of *R. crispus*.



Figs. 24–30. Diagnostic characters of *Gastrophysa polygoni*. 24. Antenna, male; 25. Antenna, female; 26. Aedeagus, dorsal view; 27. Aedeagus, lateral view; 28. Ventrite VIII, female; 29. Spermatheca; 30. Gonocoxae.

eggs were found on March 8. These adults didn't mate but were feeding and became inactive in a few days. Based on presence of eggs during early March, and assuming about one month to go through larval and pupal stages (Xiaoshui 1991), the adults would appear during early to mid-April. All of *R. nipponicus* would be dead by that time. Adults would disperse to search for suitable food plants. This could explain why only adults were observed feeding on *R. crispus* on April 13 at a different locality.

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蓼藍齒脛金花蟲 [*Gastrophysa atrocyanea* (Motschulsky, 1860)] 和萹蓄齒脛金花蟲 [*G. polygoni* (Linnaeus, 1758)] 的重新描述與蓼藍齒脛金花蟲的生物學注解 (鞘翅目：金花蟲科：金花蟲亞科)

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摘要

李奇峰。2022。蓼藍齒脛金花蟲 [*Gastrophysa atrocyanea* (Motschulsky, 1860)] 和萹蓄齒脛金花蟲 [*G. polygoni* (Linnaeus, 1758)] 的重新描述與蓼藍齒脛金花蟲的生物學注解 (鞘翅目：金花蟲科：金花蟲亞科)。台灣農業研究 71(4):281–292。

蓼藍齒脛金花蟲 (*Gastrophysa atrocyanea*) 是只在春天才出現的金花蟲；除了雄性生殖器，還針對觸角、雌蟲生殖突基節、雌蟲受精囊及雌蟲的第八腹節腹板加以描繪；並藉由跟另外一個廣泛分佈種萹蓄齒脛金花蟲 (*G. polygoni*) 相互比對，來測試這些特徵是否有診斷價值；並對此種生物學包括幼蟲及成蟲的取食行為、寄主植物及生活史提供更詳細的資料。

關鍵詞：分類學、金花蟲、蓼科、小羊蹄、皺葉酸模。

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台灣農業研究 (J. Taiwan Agric. Res.) 71(4):293–307 (2022)
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研究報告

比較農用無人飛行載具與傳統人工方式噴藥和施肥對有機青花菜生產之影響

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摘要

楊純明、劉程煒、邱凱瑩、陳楷岳、陳盈君、鄧雅靜、羅惠萍、陳怡菁。2022。比較農用無人飛行載具與傳統人工方式噴藥和施肥對有機青花菜生產之影響。台灣農業研究 71(4):293–307。

本項田間試驗係在彰化縣埤頭鄉明道大學有機農場進行，比較農用無人載具 (T) 和傳統人工 (CK) 生產管理方式，是否造成有機青花菜在生長和生產上之差異。根據 2021 年秋作田間試驗初步結果，所調查之株高、莖長、莖圍周長、葉片數、葉面積及葉面積指數等 6 項生長性狀，在此兩種管理方式之間皆未有明顯差別，且葉片、莖及全株的鮮重與乾重亦然。兩方式田間畦面萌生之雜草族群數量，在青花菜生育中期以後即無區別。比較田區四周掛置之黃色 (Y) 與藍色 (B) 黏蟲紙筒的黏捕蟲數，以 Y 之捕蟲數大於 B 之捕蟲數，而每個 Y 平均捕蟲數以 CK 田區較高，每個 B 平均捕蟲數則以 T 田區較高，然而合併 Y 與 B 之捕蟲數總和，CK 及 T 之間並無差異。有機青花菜第 1 次採收時，花莖長度平均值在處理之間未有顯著差異，第 2 次採收時以 T 區大於 CK 區，合併兩次採收資料亦以 T 區 (23.46 ± 0.54 cm) 大於 CK 區 (22.46 ± 0.54 cm)。在採收花蕾球的最大直徑上，第 1 次採收的平均值以 T 區高於 CK 區，第 2 次採收兩處理之間未有顯著差異，合併兩次資料後亦無差異。綜合兩次採收之花蕾球鮮重與花莖長度數據進行回歸分析，此兩項性狀在 CK 及 T 皆未呈現顯著一次或二次回歸關係；但是，綜合兩次採收之花蕾球鮮重與花蕾球最大直徑一次回歸分析結果，則在 CK ($R^2 = 0.415$, $P < 0.0001$) 及 T ($R^2 = 0.229$, $P < 0.0001$) 皆達顯著水準。在公頃花蕾球顆粒數，合併兩次採收數量之平均值，以 T 區 (8,047 ± 1,213 no. ha^{-1}) 高於 CK 區 (5,506 ± 711 no. ha^{-1})。在公頃花蕾球鮮重產量上，合併 2 次採收計算的平均值，亦以 T 區 (3,956 ± 639 kg ha^{-1}) 大於 CK 區 (2,531 ± 544 kg ha^{-1})。進一步分析兩種管理方式採收花蕾球的個別鮮重大小級數百分比分布情形 (分為 8 個等級)，CK 區在第 1 次採收的花蕾球以重量較小的 1–3 級分布較多、第 2 次採收則以 2–5 級分布較多，T 田區在第 1 次採收時以 2–5 級分布較多、第 2 次採收時則以 3–4 級分布較多；合併兩次採收的花蕾球數據，CK 區概以 1–5 級分布較多，合計約 94.29%，T 區則以 2–5 級分布較多，合計達 90.50%。顯示在本試驗條件下，相較於傳統人工管理方式，農用無人機管理方式可以生產出較大鮮重的花蕾球。

關鍵詞：農用無人飛行載具、農用無人機、UAV、有機青花菜、生產。

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前言

除了氣候變遷及農業氣象災害之外，農業缺工、農藥過量及高生產成本係台灣近年來面臨之三大農業問題，農政部門乃積極推動災害防護、智慧農耕科技和農用無人飛行載具 (unmanned aerial vehicle; UAV，或稱農用無人機) 操作以為因應對策，並助益於糧食生產及環境永續 (Yang 2010; Yang *et al*. 2016)。農用 UAV 應用目前尚屬新穎技術，施作條件異於傳統人工或農機操作，在慣行及有機農耕作業亦不同，許多環節仍有待釐清，才能有利於智慧農耕使用及後續推展。

由於實務需要與作業環境限制，台灣現行農用 UAV 施作多僅限於少數大面積栽培糧食作物 (如水稻、玉米) 及果樹 (如香蕉、鳳梨、龍眼、荔枝)，尚未擴及大宗蔬菜或進口替代作物，亦甚少從慣行農法延伸至有機農法。有機農業遵守自然資源循環永續利用原則、強調資源保育與生態平衡，在當前農業部門『淨零排放』路徑規劃上，具有同時降低溫室氣體排放及增加土壤碳匯雙重功能。如能將農用 UAV 擴及有機農業 (場) 之智慧農耕生產管理，將可提升有機農業栽培之生產管理效能，並有助於加速農業部門淨零排放目標之達成。

青花菜 (*Brassica oleracea* L.) 為世界各地普遍食用之十字花科蕓薹屬甘藍類蔬菜，原產於中緯度的西歐沿海一帶 (Smith 1999; Branham *et al*. 2017)，由野生甘藍變種而來，據稱在第二次世界大戰末期由美國傳入台灣栽培。迄今在台灣全年都有生產，尤以 11 月至 4 月冷涼月份為盛產期，產地集中於嘉義、彰化、雲林等地，多以傳統人工生產管理方式進行栽培 (Chen *et al*. 2013; Lin *et al*. 2014)。食用部位之花蕾球 (亦稱花苔，cluster of flowers or flower head) 及花莖富含豐富維生素、礦物質、硫配醣體 (glucosinolates) 及類黃酮 (flavonoids) 等 (Nugrahedi *et al*. 2015)，乃高纖低熱量營養蔬菜；由於市場之消費量與需求量大，不僅漸成為在地大宗消費蔬菜及重要進口替代蔬菜之一，亦被認為係可供拓展外銷之旗艦作物。除了傳統農法生產之收穫物，以有機農法生產之有機產品亦具有在地消費及外銷之無限潛力，值得進一步提升有機青花菜的生產管理技術/系統。

目前全程使用有機資材對於青花菜鮮食質量、保鮮貯藏及硝酸鹽含量等影響之有機栽培模式研究不多 (Hsieh & Hsu 1996)，許多理論基礎與應用技術仍需要深入研究開發，包括合理施肥、減量噴藥及省工加值等項目。雖然國外已多方進行無人機在農業上的研究 (Johnson *et al*. 2001; Huang *et al*. 2013; Scherer *et al*. 2017; He 2018; Meng *et al*. 2019; Tang *et al*. 2019; Teske *et al*. 2019; Li *et al*. 2021; Zhang *et al*. 2021)，台灣則相對較少。目前仍欠缺使用農用 UAV 於有機農場生產管理之青花菜應用性試驗，也尚未有可供農民/代耕業者依循、推廣之青花菜有機生產管理系統農用 UAV 標準作業流程 (standard operation procedure; SOP)，亟需早日進行創新應用之試驗研究。

本試驗旨在探討農用 UAV 和傳統人工兩種生產管理方式是否造成有機青花菜生產上的差異，俾於提供更明確科學數據作為未來建立農用 UAV 在有機青花菜 SOP 的依據。針對 2021 年秋作田間試驗，主要在於初步比較此 2 種生產管理的噴藥與施肥作業對有機青花菜生長和生產質量的影響，以利於 2022 年試驗深入評估提高肥料合理使用、農藥減量及節省人力等生產效益，進而提升未來商業化農事操作之安全性、工作效率和應用推廣。

材料與方法

2021 年秋作田間試驗係於彰化縣埤頭鄉明道大學有機農場 (23.86°N、120.49°E，海拔 33.7 m) 進行，選用早生青花菜 ‘42’ 品種參試，購自於雲林縣二崙鄉三禾育苗場。試驗處理分為農用 UAV 及傳統人工兩種生產管理方式，2 重複，每重複區 0.1 ha，田區面積共 0.4 ha，採用完全逢機設計 (complete randomized design; CRD) 排列。試驗資料之統計分析，將分別比較各調查參數之處理間差異，並區分生育期間之處理間分布。各圖比較兩處理間是否達顯著差異，以處理平均值及其標準誤 (standard error) 比較之，回歸分析引入 P 值作為檢定樣本測值的最低顯著水準，並以資料分析與繪圖

軟體 SigmaPlot 14.0 (Systat Software Inc., CA, USA) 繪製圖形。

苗株定植於鋪蓋銀黑色塑膠布之畦行，畦寬 1.2 m，畦溝寬 0.45 m。每畦種植 2 行，畦行上打孔植入青花菜苗株，行株距 0.75 m × 0.50 m。扣除畦溝及分隔畦，每種管理方式每公頃約種植 13,950 株。各區四周插上竹竿，竿上掛置黃色 (Y) 及藍色 (B) 黏蟲紙筒 (長 0.25 m、直徑 0.15 m)，約 1–2 wk 取回調查捕蟲數，並更新黏蟲紙筒。蟲害管理另加上蘇力菌噴施處理，每隔 2–3 wk 實施 1 次 (表 1)。田間除草每隔 1–2 wk 實施 1 次，畦面雜草以

表 1. 2021 年秋作有機青花菜田間試驗栽培時間曆 (2021 年 10–12 月)。

Table 1. Cultivation calendar of field trial of organic broccoli in Fall Crop 2021 (October–December 2021).

Date	Item	Content
10/09	Land preparation	First time land preparation and irrigation
10/12	Land preparation	Second time land preparation; applied basal dose of fertilizer
10/17	Furrows making	Making furrows with spacing of 1.2 m and ditch width of 0.45 m; cover furrows with black plastic film and dig holes for seedling transplanting, two parallel rows per furrow with in-row distance 0.75 m
10/18	Transplanting and first sampling	Seedling transplanting with spacing of 0.75 m × 0.50 m and irrigated after transplanting; first sampling
10/26	Weeding	First hand weeding on furrows and weighted the harvested weeds
11/01	Biopesticide spraying	First spraying of *Bacillus thuringiensis* by unmanned aerial vehicle (UAV) or human labor
11/02	Insects collecting	Attach yellow (Y) and blue (B) sticky paper traps around the plots of the organic broccoli field
11/02	Weeding	Second hand weeding on furrows and weighted the harvested weeds
11/09	Top dressing	Applying first top dressing of liquid organic fertilizer by UAV or human labor
11/09	Weeding	Third hand weeding on furrows and weighted the harvested weeds
11/10	Second sampling	Second sampling at 23 d after transplanting
11/15	Biopesticide spraying	Second spraying of *B. thuringiensis* by UAV or human labor
11/16	Insects counting	Bring back yellow (Y) and blue (B) sticky paper traps for insects counting
11/16	Insects collecting	Attach yellow (Y) and blue (B) sticky paper traps around the plots of the organic broccoli field
11/23	Insects counting	Bring back yellow (Y) and blue (B) sticky paper traps for insects counting
11/23	Weeding	Fourth hand weeding on furrows and weighted the harvested weeds
11/25	Top dressing	Applying second top dressing of liquid organic fertilizer by UAV or human labor
11/30	Insects collecting	Attach yellow (Y) and blue (B) sticky paper traps around the plots of the organic broccoli field
11/30	Weeding	Fifth hand weeding on furrows and weighted the harvested weeds
12/03	Third sampling	Third sampling at 46 d after transplanting,
12/07	Insects counting	Bring back yellow (Y) and blue (B) sticky paper traps for insects counting
12/07	Weeding	Sixth hand weeding on furrows and weighted the harvested weeds
12/07	Biopesticide spraying	Third spraying of *B. thuringiensis* by UAV or human labor
12/08	Irrigation	Irrigation in the afternoon
12/14	Top dressing	Applying third top dressing of liquid organic fertilizer by UAV or human labor
12/14	Insects collecting	Attach yellow (Y) and blue (B) sticky paper traps around the plots of the organic broccoli field
12/14	Weeding	Seventh hand weeding on furrows and weighted the harvested weeds
12/16	Fourth sampling	Fourth sampling at 59 d after transplanting
12/17	First harvest	First time harvest of flower heads
12/24	Second harvest	Second time harvest of flower heads
12/24	Insects counting	Bring back yellow (Y) and blue (B) sticky paper traps for insects counting

人工拔 (割) 除方式清除，並秤取雜草族群的鮮重與乾重 (表 1)。畦溝雜草則以手持式除草機及長柄鐮刀去除移走，不予秤重。試驗田區採畦溝灌溉方式，第 1 次整地後、苗株定植後及採收前 9 d 各分別灌溉 1 次。秋作栽培時間曆如表 1，兩種生產管理方式比較如表 2。

本試驗所使用的農用 UAV 為 Agras T16 (DJI 大疆創新，深圳，中國大陸) 6 軸鑽石型設計槳葉，選用任務飛行模式，飛行速率約 1.8 m s^{-1}，飛行高度距離青花菜植株頂端約 2.5 m (表 2)。噴灑系統配備 4 個液泵及 8 個 IDK120015 抗飄散噴頭 (Lechler GmbH, Metzingen, Germany)，噴嘴幅寬 120 度，流量最高可達 4.8 L min^{-1}。農用 UAV 操作時之氣象環境紀錄如表 3。

於青花菜栽植前，試驗田的採樣土壤先經過前處理後，再行物化性質分析。土壤酸鹼度 (pH) 依土水比 1：1 法測定 (McLean 1982)，電導度 (electrical conductivity; EC) 按土水比 1：5 萃取後測定 (Rhoades 1982)，土壤有機質按照 Walkley-Black 法測定 (Nelson & Sommers 1996)，土壤質地以比重計法測得 (Gee & Bauder 1986)，無機態氮 (硝酸態氮及銨態氮) 則利用 2 N KCl 萃取後，以化學分析儀 (Smartchem 140, Systea S.p.A., Anagni, Italy) 測定，有效性磷及交換性陽離子鈣、鎂、鉀以及交換性重金屬 (銅、鋅、鎘、鉻、鎳、鉛)，以孟立克法萃取後，以感應耦合電漿原子放射光譜儀 (Inductively Coupled Plasma Atomic Emission Spectroscopy; ICP-AES) 測定 (Mehlich

表 2.　2021 年秋作有機青花菜田間試驗之農用無人機與傳統人工生產管理方式比較。

Table 2.　Comparison of differences between agricultural drones and traditional human labor management practices for field trial of organic broccoli in Fall Crop 2021.

Item	Practice	Dose	Amount of water	Dilution factor	Date	Duration (s)
Spraying of *Bacillus thuringiensis*	UAV[y]	80 g	8 L	100	2021/11/01	243
					2021/11/15	218
					2021/12/07	225
					2021/12/15	274
	Human labor[x]	80 g	80 L	1,000	2021/11/02	3,060
					2021/11/15	3,066
					2021/12/07	3,082
					2021/12/15	2,948
Applying of organic liquid fertilizer[z]	UAV	500 mL	10 L	20	2021/11/09	243
					2021/11/25	249
					2021/12/14	246
	Human labor	500 mL	80 L	160	2021/11/09	3,342
					2021/11/25	3,076
					2021/12/14	2,886

[z] Organic liquid fertilizer “Jinfengshou (5-15)”, JF Biotechnology Company, Pingtung County, Taiwan. Ingredients: meat and bone meal, soybean meal, and rice bran. Compositions: total nitrogen 3.9%, total phosphoric anhydride 3.9%, total potassium oxide 2.1%, and organic matter 30.0%.
[y] by agricultural unmanned aerial vehicle (UAV) (0.2 ha, 1 person; nozzle distance from plant height 2.5 m).
[x] by traditional manual knapsack sprayer (0.2 ha, 2 persons; nozzle distance from plant height 5–10 cm).

表 3.　2021 年秋作有機青花菜田間試驗農用無人機操作之氣象環境。

Table 3.　Meteorological environment for the operation of agricultural drone for organic broccoli field trial in the Fall Crop 2021.

Air temperature(℃)	Wind speed (km h^{-1})	Rainfall probability (%)	Visibility (km)
15–28	6–32	0	16

1984)，分析結果如表 4。田區灌溉水之理化性質分析，係以 pH meter 測定酸鹼度、EC meter 測定電導度、總有機碳分析儀測定總碳及 ICP-AES 分析陽離子 (鐵、錳、銅、鋅、鉀、鈉、鈣、鎂、鎘、鉻、鎳、鉛) 總量，結果如表 5。

本試驗全程施用有機肥料，基肥選用綠林牌好康 6-3-3-85 混合有機質肥料 (綠林生物科技股份有限公司，台灣彰化縣)，於青花菜種植前 6 d (2021 年 10 月 12 日) 施入田區，施用量 2,000 kg ha^{-1}。追肥選用金豐收液態有機質肥料 (5-15) (金峰生物科技有限公司，台灣屏東縣)，標示原料名稱：肉骨粉、豆粕、米糠，登記成分：全氮 3.9%、全磷酐 3.9%、全氧化鉀 2.1%、有機質 30.0%。各處理於每次葉面追肥時，分別記錄單位面積用水量及噴灑時間 (參見表 2)。

本試驗青花菜生育期間，取樣調查植株的生長性狀 (表 1)，除了定植日各處理取樣苗株 30 株之外，其餘取樣日各處理各重複區逢機取樣 10 株，調查：(1) 株高 (plant height, cm)：由地表至植株最高處，(2) 莖長 (stalk length, cm)：由地表至花蕾球基部，(3) 花莖圓周長 (stalk circumference, cm)：花莖基部的圓周長，(4) 葉片數 (leaf number, no. pl^{-1})：青綠色葉片數，(5) 葉面積 (leaf area, m^2 pl^{-1})：植株葉片合計面積，(6) 葉面積指數 (leaf area index, m^2 m^{-2})：單位農地面積上的植株葉面積。

本試驗採收兩次花蕾球，每次採收時，計算各重複區收取之花蕾球數目 (number of flower heads, no. $block^{-1}$)，並量測每顆花蕾球之最長直徑 (maximum diameter, cm)、花莖長 (flower stalk length, cm) 及鮮重 (fresh weight, g)。每次採收，各處理各重複區逢機收取 3 塊 13.5 m^2 面積樣區植株之花蕾球，合併計算，並推估公頃花蕾球顆粒數及公頃鮮重產量。採收之花蕾球並將依照鮮重高低劃分 8 等級 (level)，計算各級別花蕾球數量百分比及繪製分布圖。第 1 次及第 2 次採收標準分別設定為最長直徑 12 cm 以上及 10 cm 以上的花蕾球，單粒鮮重等級由低至高劃分為：level 1 (≤ 300 g $head^{-1}$)，level 2 (301–400 g $head^{-1}$)，level 3 (401–500 g $head^{-1}$)，level 4 (501–600 g $head^{-1}$)，level 5 (601–700 g $head^{-1}$)，level 6 (701–800 g $head^{-1}$)，level 7 (801–900 g $head^{-1}$)，level 8 (≥ 901 g $head^{-1}$)。

表 4. 試驗田區土壤之物化性質。

Table 4. Physicochemical properties of soil in the experimental field.

Soil property	Value
pH (1 : 1)	7.63
EC (1 : 5) (ds m^{-1})	0.10
Organic matter (%)	2.32
Texture	Sandy loam
NO_3-N (mg kg^{-1})	37.80
NH_4-N (mg kg^{-1})	94.30
Available P (mg kg^{-1})	59.00
Exchangeable K (mg kg^{-1})	97.00
Exchangeable Ca (mg kg^{-1})	3,260.00
Exchangeable Mg (mg kg^{-1})	165.00
Exchangeable Cu (mg kg^{-1})	5.30
Exchangeable Zn (mg kg^{-1})	2.90
Exchangeable Cd (mg kg^{-1})	0.06
Exchangeable Cr (mg kg^{-1})	0.65
Exchangeable Ni (mg kg^{-1})	1.20
Exchangeable Pb (mg kg^{-1})	6.50

表 5. 灌溉水之理化性質。

Table 5. Physicochemical properties of irrigation water.

Property of irrigation water	Value
pH	6.92
EC (ds m^{-1})	1.36
Total carbon (mg L^{-1})	50.90
Exchangeable K (mg L^{-1})	6.80
Exchangeable Na (mg L^{-1})	13.20
Exchangeable Ca (mg L^{-1})	240.00
Exchangeable Mg (mg L^{-1})	59.30
Exchangeable Fe (mg L^{-1})	ND[z]
Exchangeable Mn (mg L^{-1})	0.33
Exchangeable Cu (mg L^{-1})	0.78
Exchangeable Zn (mg L^{1})	ND
Exchangeable Cd (mg L^{-1})	ND
Exchangeable Cr (mg L^{-1})	ND
Exchangeable Ni (mg L^{-1})	ND
Exchangeable Pb (mg L^{-1})	ND

[z] ND: not detectable.

結果與討論

本項田間試驗係在彰化縣埤頭鄉明道大學有機農場進行，比較農用 UAV (T) 和傳統人工 (CK) 兩種生產管理方式，是否造成有機青花菜在生長和生產上之差異。2021 年秋作試驗係自 10 月 18 日青花菜苗定植起，至 12 月 17 日做第 1 次花蕾球採收，12 月 24 日做第 2 次花蕾球採收，其間亦進行多次植株取樣調查生長性狀 (表 1)。根據初步結果，經取樣調查定植後不同日數植株之株高、莖長、莖圓周長、葉片數、葉面積及葉面積指數等生長性狀變化，發現此 6 項生長性狀皆隨著植株的生長進程而增加，惟葉面積及葉面積指數約在定植後 42 d 開始下降，直至花蕾球採收 (圖 1)，兩種生產管理方式的植株之間未有明顯生長差異。

再檢視秤量之葉片、莖及全株的鮮重與乾重，大致上此兩種管理方式之間亦未有顯著差異，皆在初期緩慢生長，至定植後 19 d 起快速成長，秤量性狀之間幾呈平行增加趨勢 (圖 2)。由此顯示，在使用相同劑量的有機基肥、有機液肥及有機製劑 (蘇力菌) 下，T 之管理操作並未形成所調查生長性狀與生質量的落後，T 及 CK 田區有近似之植株生長表現。

兩種管理方式皆以人力清除田間畦面上雜草，由鋪蓋田畦的銀黑色塑膠布栽植孔萌生之雜草，自定植後至 19 d 具有較多雜草族群數量，且以 CK 區的畦面雜草數量高於 T 區 (圖

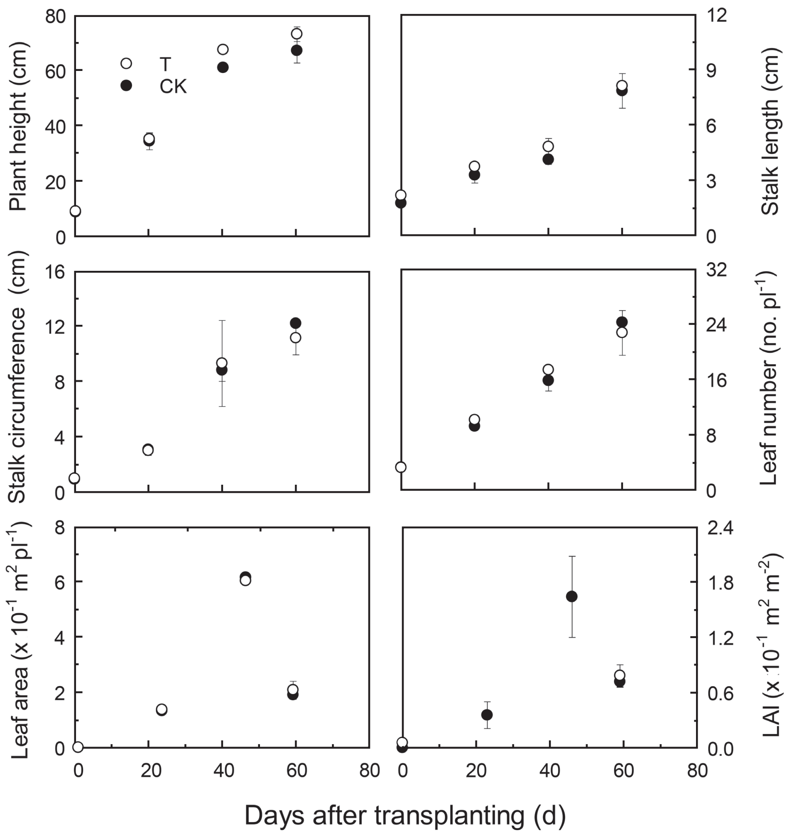

圖 1.　彰化縣埤頭鄉明道大學有機農場 2021 年有機青花菜秋作田區以農用無人機 (T) 和傳統人工 (CK) 生產管理方式於定植後不同日數取樣調查植株之株高 (plant height)、莖長 (stalk length)、莖圓周長 (stalk circumference)、葉片數 (leaf number)、葉面積 (leaf area) 及葉面積指數 (leaf area index; LAI) 的變化。

Fig. 1.　Changes in plant height, stalk length, stalk circumference, leaf number per plant, leaf area and leaf area index (LAI) at different days after seedling transplanting of broccoli, using agricultural drone (T) and traditional human labor (CK) management practices, grown in MingDao University Organic Farm located at Pitou Township of Changhua County in Fall Crop 2021.

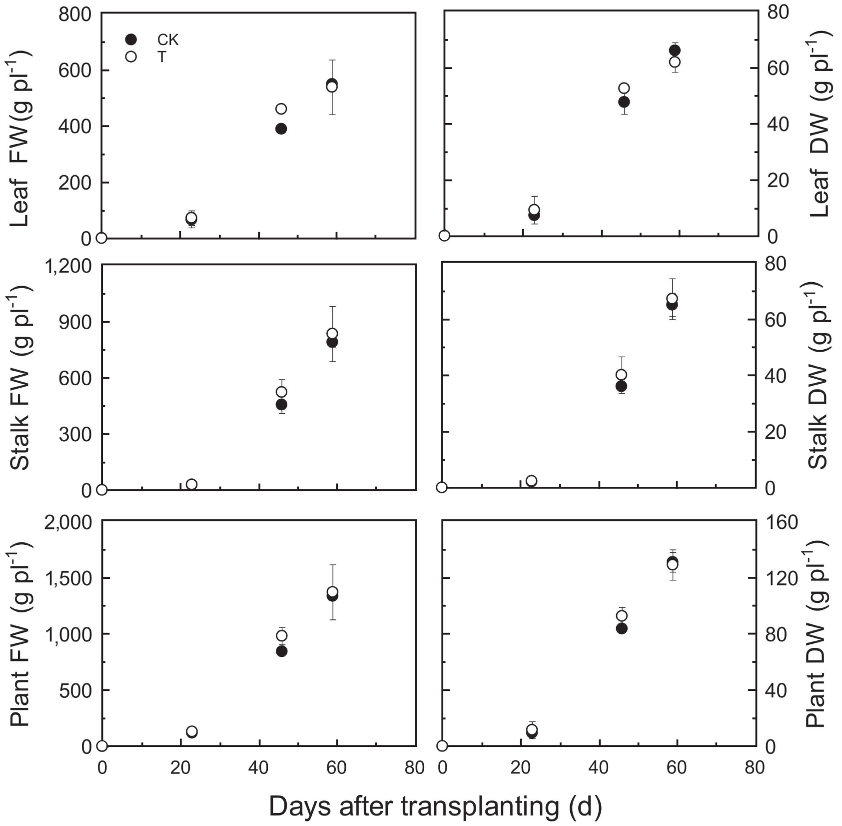

圖 2. 彰化縣埤頭鄉明道大學有機農場 2021 年有機青花菜秋作田區以農用無人機 (T) 和傳統人工 (CK) 生產管理方式於定植後不同日數取樣調查之植株葉片、莖及全株的鮮重與乾重。

Fig. 2. Changes in fresh and dry weights (FW and DW) of leaves, stalks and plants at different days after seedling transplanting of broccoli, using agricultural drone (T) and traditional human labor (CK) management practices, grown in MingDao University Organic Farm located at Pitou Township of Changhua County in Fall Crop 2021.

3)。青花菜生育中期以後，兩種管理方式之畦面雜草數量則無明顯差別，且皆隨著青花菜植株體積的伸展擴大，而雜草族群數量漸趨減少直至收穫。由此可知，在青花菜幼株的初期生育階段，CK 管理方式可能因為噴灑的水量較多，有利於較多雜草族群萌生，於是拔取較高雜草數量 (鮮重)。當青花菜植株長成後，即具有較大的競爭潛力，反饋遮蔽限制雜草的生長，因此雜草族群數量逐漸下降，且兩種管理方式之間亦未有顯著差異。顯見任一管理方式，似未特別促進雜草族群數量的繁衍，而且當青花菜植株的生長進程與植體伸展逐漸擴大覆蓋，致使得雜草族群數量漸減時，似乎即未對青花菜的生育產生明顯干擾。

本試驗有機青花菜田區之害蟲管理以蘇力菌及掛置黏蟲紙筒為主，前者透過農用 UAV 灑施或傳統人工方式噴施，後者乃在田區四周同時掛置黃色 (Y) 與藍色 (B) 黏蟲紙筒黏捕害蟲族群，據以粗估兩種管理方式之害蟲族群數量。試驗發現，兩種管理方式之 Y 黏蟲紙筒捕蟲數大於 B 黏蟲紙筒捕蟲數，且每個 Y 黏蟲紙筒平均捕蟲數以 CK 田區較高；而每個 B 黏蟲紙筒平均捕蟲數，則以 T 田區有較高數量 (圖 4)。惟合併 Y 及 B 黏蟲紙筒之捕蟲數總和，CK 及 T 田區之間無明顯區分，顯示 2 種管理方式並未造成青花菜田間黏捕蟲數量上的差異。雖然不同顏色黏蟲紙筒黏捕的蟲類可能不同、蟲數也不相等，但是兩種管理方式黏捕蟲數總和之間並無顯著差異，故推測此兩種管理方式可能有類似的害蟲管理效果及害蟲的影響。

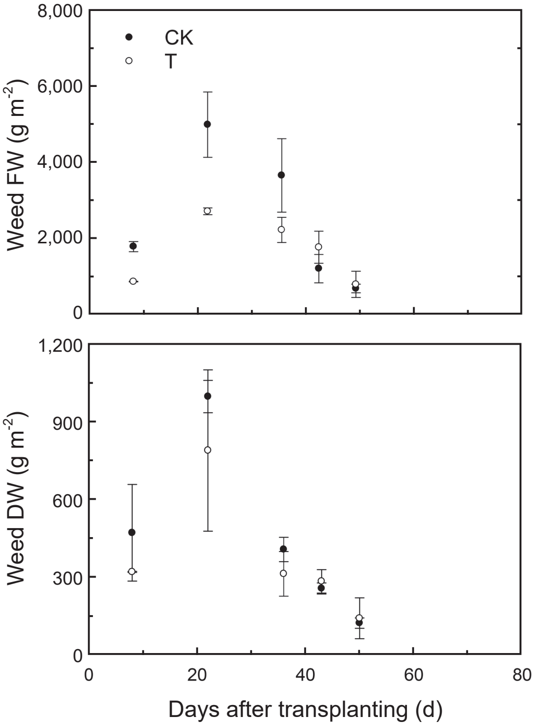

圖 3.　彰化縣埤頭鄉明道大學有機農場 2021 年有機青花菜秋作田區以農用無人機 (T) 和傳統人工 (CK) 生產管理方式於定植後不同日數於畦面調查之單位面積 (m^2) 雜草族群的鮮重與乾重。

Fig. 3.　Changes in fresh and dry weights (FW and DW) of weeds collected from furrows of experimental fields at different days after seedling transplanting of broccoli, using agricultural drone (T) and traditional human labor (CK) management practices, grown in Ming-Dao University Organic Farm located at Pitou Township of Changhua County in Fall Crop 2021.

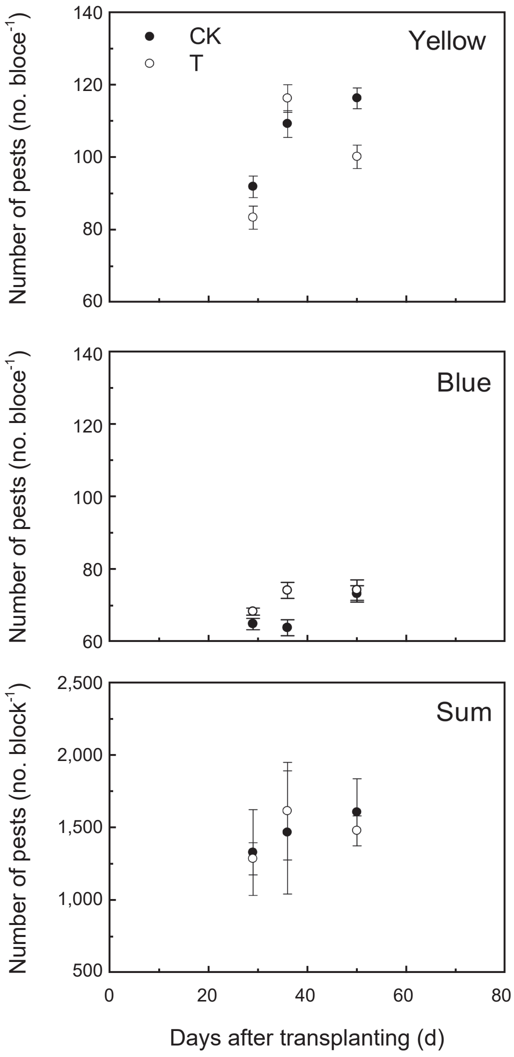

圖 4.　彰化縣埤頭鄉明道大學有機農場 2021 年有機青花菜秋作田區以農用無人機 (T) 和傳統人工 (CK) 生產管理於定植後不同日數調查之黃色 (Yellow) 及藍色 (Blue) 黏蟲紙筒的捕蟲數及總合 (Sum)。

Fig. 4.　Changes in counts of insects caught by yellow and blue sticky paper traps from experimental fields at different days after seedling transplanting of broccoli, using agricultural drone (T) and traditional human labor (CK) management practices, grown in MingDao University Organic Farm located at Pitou Township of Changhua County in Fall Crop 2021.

本試驗採收 2 次花蕾球，皆調查花蕾球之最大直徑與平均值、花莖長度與平均值、每顆花蕾球鮮重及花蕾球鮮重總和 (換算公頃產量)。根據調查結果，第 1 次採收 (I) 之花莖長度平均值在處理之間未有顯著差異 (CK：22.71 ± 0.80 cm, T：23.44 ± 1.03 cm)，第 2 次採收 (II) 以 T 處理區 (T, 23.49 ± 0.34 cm) 植株的花莖長度平均值大於 CK 處理區 (CK, 22.20 ± 0.51 cm) 者 (圖 5)。合併 2 次採收資料比較，亦以 T 區 (23.46 ± 0.54 cm) 相較於 CK 區 (22.46 ± 0.54 cm) 有較大的花莖長度平均值。

在採收花蕾球的最大直徑量測上，第 1 次採收花蕾球最大直徑的平均值以 T 區 (19.36 ± 1.11 cm) 高於 CK 區 (17.36 ± 0.40 cm)，第 2 次採收時兩處理之間未有差異 (CK：19.10 ± 0.55 cm, T：19.17 ± 0.11 cm) (圖 6)。合併 2

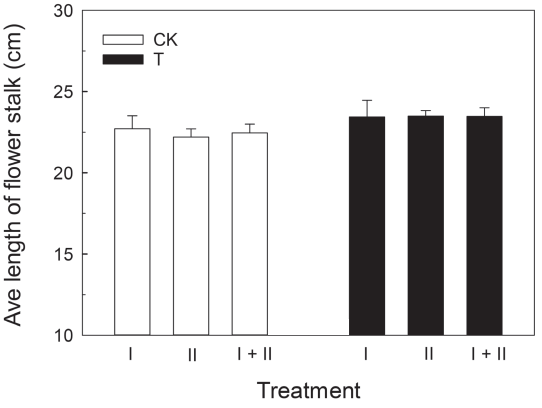

圖 5. 2021 年秋作有機青花菜第 1 次採收 (I，12/17/2021)、第 2 次採收 (II，12/24/2021) 及合併兩次採收 (I + II) 之花莖平均長度。CK：傳統人工施肥及噴藥處理方式，T：農用無人機施肥及噴藥處理方式。採收標準第 1 次設定為花蕾球最大直徑為 12 cm 以上者、第 2 次則為花蕾球最大直徑為 10 cm 以上者。

Fig. 5. Comparison of differences in the average values of length of flower stalks of organic broccoli between agricultural drone (T) and traditional human labor (CK) management practices harvested in the first harvest (I, 12/17/2021), the second harvest (II, 12/24/2021) and pooled data (I + II) for field trial in Fall Crop 2021. The first and the second harvests collected flower heads with the maximum diameter greater than 12 cm and 10 cm, respectively.

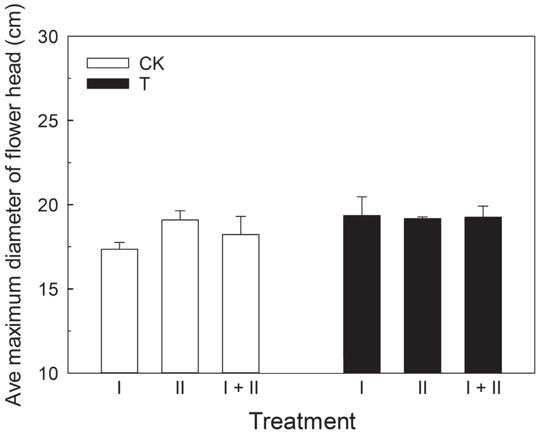

圖 6. 2021 年秋作有機青花菜第一次採收 (I，12/17/2021)、第二次採收 (II，12/24/2021) 及兩次採收 (I + II) 之花蕾球平均最大直徑。CK：傳統人工施肥及噴藥處理方式，T：農用無人機施肥及噴藥處理方式。採收標準第 1 次設定為花蕾球最大直徑為 12 cm 以上者、第 2 次則為花蕾球最大直徑為 10 cm 以上者。

Fig. 6. Comparison of differences in the average values of maximum diameter of flower heads of organic broccoli between agricultural drone (T) and traditional human labor (CK) management practices harvested in the first harvest (I, 12/17/2021), the second harvest (II, 12/24/2021) and pooled data (I + II) for field trial in Fall Crop 2021. The first and the second harvests collected flower heads with the maximum diameter greater than 12 cm and 10 cm, respectively.

次資料比較，則花蕾球最大直徑的平均值在兩種處理方式之間未呈現顯著差異 (CK：18.23 ± 1.08 cm, T：19.26 ± 0.65 cm)。由此可知，雖然 T 處理在第 1 次採收時獲得較大的花蕾球顆粒直徑，但是綜合 2 次採收的花蕾球顆粒最大直徑平均值，則此兩種管理方式於統計上未有顯著不同。

又綜合 2 次採收之花蕾球鮮重與花莖長度數據進行回歸分析比較 (圖 7)，發現無論係 CK 處理 (R^2 = 0.0023, P = 2.117) 或 T 處理 (R^2 = 0.033, P = 0.0001)，此兩項性狀之間皆未呈現明顯之一次回歸關係，亦未有二次回歸關係 (資料未列出)。因此，本試驗 2 種生產管理方式在花蕾球採收時，皆不宜以當時的花莖長度推估花蕾球鮮重。然而，綜合 2 次採收之花蕾球鮮重與花蕾球最大直徑之一次回歸分析結果，則此 2 性狀在 CK (R^2 = 0.415, P < 0.0001) 及 T (R^2 = 0.229, P < 0.0001) 管理方式下，皆達到顯著水準 (圖 8)。因此，本試驗兩種生產管理方式在花蕾球採收時，如有需要時，皆可以當時的花蕾球最大直徑推估花蕾球鮮重。

在公頃花蕾球顆粒數的比較上，第 1 次及第 2 次採收的花蕾球顆粒數量皆以 T 田區高於 CK 田區 (圖 9A)，但是統計上未達顯著性差異。如將 2 次採收花蕾球合併計算其平均值，則 T 田區 (8,047 ± 1,213 no. ha^{-1}) 的花蕾球顆粒數高於 CK 田區 (5,506 ± 711 no. ha^{-1}) 者。另在公頃花蕾球鮮重產量上，T 田區 (4,407 ± 1,542 kg ha^{-1}) 第 1 次採收的鮮重產量大於 CK 田區 (2,146 ± 482 kg ha^{-1})，第 2 次採收則兩處理田區之間未有差異 (圖 9B)。但是，合併兩次採收計算的花蕾球鮮重平均值，仍以 T 田區 (3,956 ± 639 kg ha^{-1}) 大於 CK 田區 (2,531 ± 544 kg ha^{-1})。因此，整體而言，相較於 CK

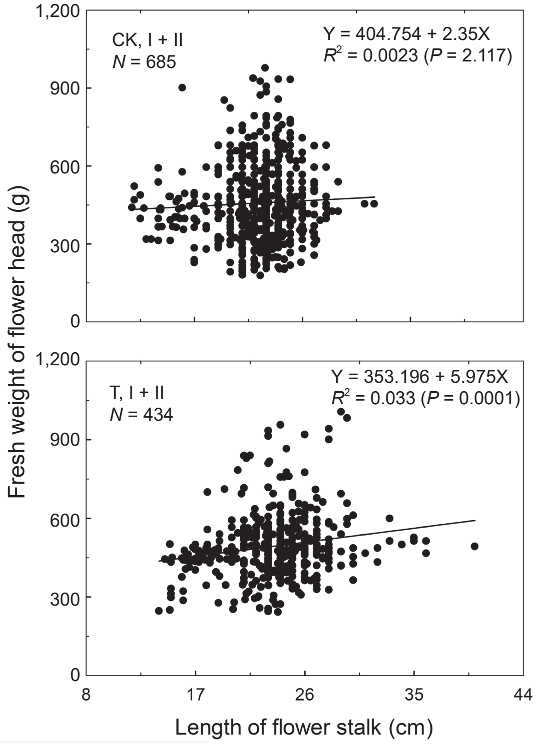

圖 7. 2021 年秋作有機青花菜第 1 次採收 (I，12/17/2021) 及第 2 次採收 (II，12/24/2021) 合併數據 (I + II) 之花莖長度與花蕾球鮮重之一次回歸關係圖。CK：傳統人工施肥及噴藥處理方式，T：農用無人機施肥及噴藥處理方式。

Fig. 7. Linear regression analyses between length of flower stalks and fresh weight of flower heads collected from the field trial with agricultural drone (T) and traditional human labor (CK) management practices in both the first (I, 12/17/2021) and the second (II, 12/24/2021) harvests in Fall Crop 2021.

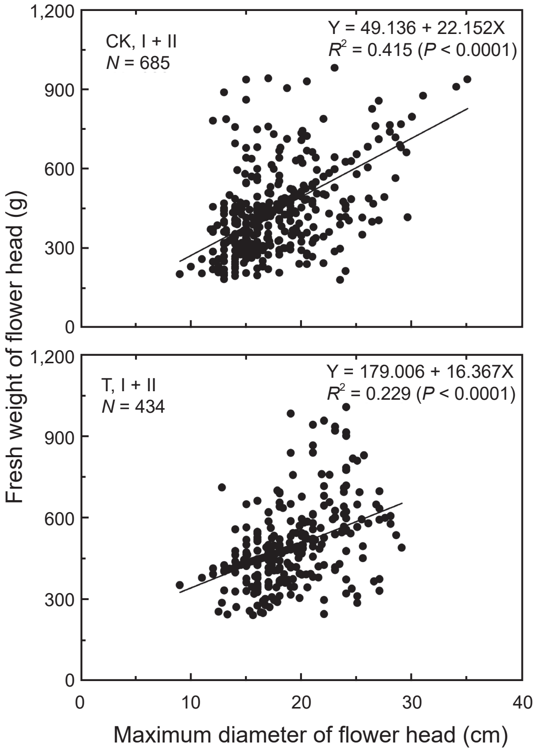

圖 8. 2021 年秋作有機青花菜第 1 次採收 (I，12/17/2021) 及第 2 次採收 (II，12/24/2021) 合併數據 (I + II) 之花蕾球直徑與花蕾球鮮重之一次回歸關係圖。CK：傳統人工施肥及噴藥處理方式，T：農用無人機施肥及噴藥處理方式。

Fig. 8. Linear regression analyses between the maximum diameter and fresh weight of flower heads collected from the field trial with agricultural drone (T) and traditional human labor (CK) management practices in both the first (I, 12/17/2021) and the second (II, 12/24/2021) harvests in Fall Crop 2021.

田區，本試驗有機青花菜在 T 管理方式下可以採收較多的花蕾球顆粒數量及較高的花蕾球鮮重產量。雖然 T 處理噴灑的霧狀水分顆粒較小、濃度較高，是否因此造成不等肥效與藥效，形成花蕾球顆粒數和鮮重上的差異，或另有其他因素，仍需多期作試驗觀察與比較才能評估。

本試驗將採收的花蕾球依照個別顆粒鮮重高低區分為 8 等級，以進一步比較兩種管理田區採收花蕾球重量大小級數百分比分布情形 (圖 10)。結果顯示，CK 田區在第 1 次採收的花蕾球以重量較小的 1–3 級分布較多 (19.55 ± 12.76%、30.48 ± 7.75%、29.39 ± 10.54%)，在第 2 次採收的花蕾球則以 2–5 級分布較多 (23.52 ± 4.45%、38.10 ± 6.73%、21.88 ± 9.39%、11.16 ± 0.97%)。T 田區在第 1 次採收時以 2–5 級分布較多 (23.45 ± 1.86%、26.98 ± 7.18%、18.79 ± 9.06%、11.82 ± 0.56%)，第 2 次採收時則以 3–4 級分布較多 (64.72 ± 7.60%、30.89 ± 1.39%)。合併兩次採收的花蕾球數據，CK 田區概以 1–5 級分布較多 (10.48 ± 12.83%、27.00 ± 4.92%、33.74 ± 6.16%、14.61 ± 10.28%、8.46 ± 3.82%)，合計約 94.29%，T 田區則以 2–5 級分布較多 (13.10 ± 14.64%、

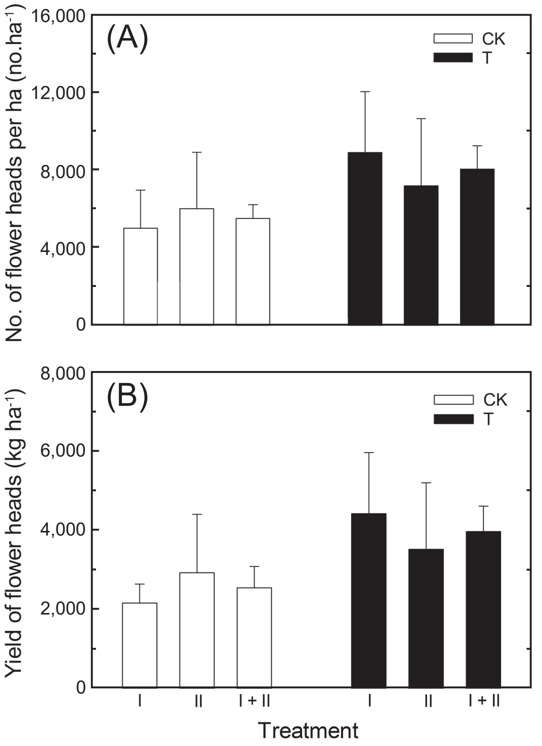

圖 9. 2021 年秋作有機青花菜第一次採收 (I，12/17/2021)、第二次採收 (II，12/24/2021) 及合併 2 次採收 (I + II) 之 (A) 公頃花蕾球顆粒數和 (B) 鮮重產量。CK：傳統人工施肥及噴藥處理方式，T：農用無人機施肥及噴藥處理方式。

Fig. 9. Comparison of differences in the number of flower heads per ha and yield of flower heads of organic broccoli between agricultural drone (T) and traditional human labor (CK) management practices harvested in the first harvest (I, 12/17/2021), the second harvest (II, 12/24/2021) and pooled data (I + II) for field trial in Fall Crop 2021.

45.85 ± 26.68%、24.82 ± 8.56%、6.73 ± 7.19%)，合計達 90.50%。整合此一有機青花菜秋作試驗結果可知，在本項試驗條件下，相較於傳統人工管理方式，農用 UAV 管理方式可以生產出較多的較大顆粒鮮重花蕾球。此外，由於農用 UAV 管理方式具有諸如省時、省工、節能、節水等多項優勢 (參見表 2)，有助於降低生產成本，因此作者將持續進行 2022 年春作及秋作試驗，以釐清此 2 種生產管理方式成本效益上之差異。

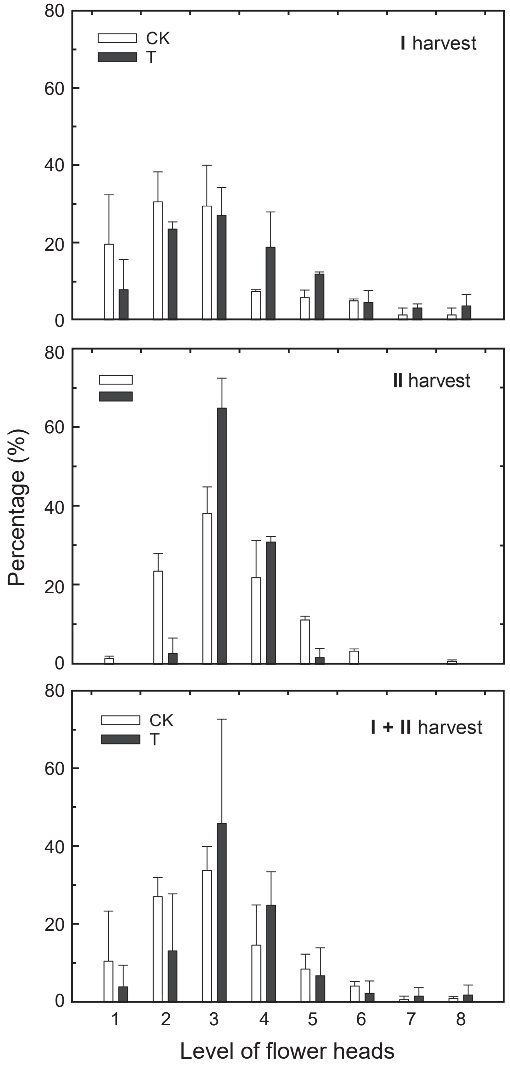

圖 10. 2021 年秋作有機青花菜第一次採收 (I，12/17/2021)、第二次採收 (II，12/24/2021) 及合併 2 次採收 (I + II) 之花蕾球重量大小級數百分比分布之處理間比較。CK：傳統人工施肥及噴藥處理方式，T：農用無人機施肥及噴藥處理方式。本試驗採收的個別花蕾球鮮重大小劃分為 8 等級：級數 1，≤ 300 g head^{-1}；級數 2，301–400 g head^{-1}；級數 3，401–500 g head^{-1}；級數 4，501–600 g head^{-1}；級數 5，601–700 g head^{-1}；級數 6，701–800 g head^{-1}；級數 7，801–900 g head^{-1}；級數 8，≥ 901 g head^{-1}。

Fig. 10. Comparison of differential distribution of percentage of fresh weight levels of flower heads of organic broccoli between agricultural drone (T) and traditional human labor (CK) management practices in the first harvest (I, 12/17/2021), the second harvest (II, 12/24/2021) and pooled data (I + II) for field trial in Fall Crop 2021.

結論

綜合本項 2021 年有機青花菜秋作試驗結果，在相同有機基肥、有機液肥及有機製劑 (蘇力菌) 之使用劑量下，雖然使用水量較少，農用 UAV 生產管理方式和傳統人工生產管理方式在植株生長、田間畦面雜草族群數量及黏捕蟲數目上並未出現明顯差別。在生產表現上，UAV 管理方式田區採收之花莖長度平均值較大，而雖然花蕾球顆粒的最大直徑平均值未有顯著差異，但是 2 次採收合併計算之公頃顆粒數平均值及公頃鮮重產量平均值均較高。進一步分析原因，顯示在本項試驗條件下，農用 UAV 生產管理方式可以生產出較多百分比之較大顆粒鮮重的花蕾球。試驗又發現，兩種管理方式在採收時之花蕾球鮮重與花蕾球最大直徑之間呈現線性回歸關係，皆可以當時的花蕾球最大直徑推估花蕾球鮮重。至於花蕾球公頃顆粒數及公頃鮮重上的差異，仍待未來多作季資料進一步評估。

誌謝

本計畫『農用無人飛行載具 (UAV) 於有機青花菜生產管理之創新應用研究』，計畫編號 110 農科-8.3.2-科-a9，承蒙行政院農業委員會計畫經費補助，特申謝忱。試驗期間又有多位明道大學智慧暨精緻農業學系同學協助取樣調查，謹一併致謝。

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Comparison of Agricultural Unmanned Aerial Vehicle (UAV) and Traditional Human Labor for Biopesticide Spraying and Fertilization on the Effect of Organic Broccoli Production

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Abstract

Yang, C. M., C. W. Liu, K. Y. Chiu, K. Y. Chen, Y. C. Chen, Y. C. Teng, H. P. Lo, and Y. J. Chen. 2022. Comparison of agricultural unmanned aerial vehicle (UAV) and traditional human labor for biopesticide spraying and fertilization on the effect of organic broccoli production. J. Taiwan Agric. Res. 71(4):293–307.

A field experiment was carried out at an Organic Farm of Mingdao University, Pitou Township, Changhua County. Two field management practices, agricultural unmanned aerial vehicle (or agricultural drone; T) and traditional human labor (CK) for biopesticide spraying and fertilization, were compared to evaluate the differences in the growth and production of organic broccoli. According to the preliminary results of Fall Crop in 2021, there were no significant differences between the two management practices in plant height, stalk length, stalk circumference, leaf number, leaf area, and leaf area index. All traits followed a similar trend as the growth progressed, indicating that the T-managed practice did not cause a significant growth lag in the investigated growth traits relative to those of the CK practice. There was generally no significant difference between the two practices in the fresh weight and dry weight of leaves, stalks, and the whole plant along plant development. Both practices used hand weeding to remove weeds that emerged on the furrows of the field plots. It showed that the furrows with CK practice 19 d after seedling transplanting had a higher weed population. After that, no difference was found between the two practices, and the weed population gradually decreased with the expansion of the broccoli plant size. From the counts of insects caught by yellow (Y) and blue (B) sticky paper traps hanging around the plots of the field, it was shown that counts of insects caught by Y paper traps were greater than that of the B paper traps in the plots of both practices. The average counts of insects caught by each Y paper trap were higher in plots of CK, while the average counts of insects caught by each B paper trap were higher in plots of T. There was no significant difference in the total counts of insects caught by Y plus B paper traps between two management fields. In the first harvest of flower heads (I, 12/17/2021), no difference was found in the average values of the length of flower stalks between practices. In the second harvest (II, 12/24/2021), the average value of the length of flower stalks of T (23.49 ± 0.34 cm) was longer than that of CK (22.20 ± 0.51 cm). The pooled data of two harvests also showed that T (23.46 ± 0.54 cm) had a higher value than CK (22.46 ± 0.54 cm). When the longest diameter of harvested flower heads were compared, the average value of T (19.36 ± 1.11 cm) was higher than that of CK (17.36 ± 0.40 cm) in the first harvest, but not in the second harvest, nor in pooled data of two harvests. By the regression analyses between the fresh weight of flower

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heads and the length of flower stalks of pooled data, there exists no relationship in both the first- and the second-order regression models. However, the regression between fresh weight of flower heads and longest diameter of flower heads showed a significant linear relationship, in both CK (R^2 = 0.415, P < 0.0001) and T (R^2 = 0.229, P < 0.0001). With pooled data of two harvests, results indicated that T practice (8,047 ± 1,213 no. ha^{-1}) collected more flower heads than CK practice (5,506 ± 711 no. ha^{-1}), as well as in the yield of fresh flower heads, 3,956 ± 639 kg ha^{-1} for T and 2,531 ± 544 kg ha^{-1} for CK. Comparing the percentage distributions of different levels (fresh weights) of flower heads collected in two harvests of both management fields, from level 1 to level 8 (from small to large), it was shown that CK practice collected more flower heads of level 1–3 in the first harvest and level 2–5 in the second harvest. For T practice, it collected more flower heads of levels 2–5 and levels 3–4 in the first and the second harvests, respectively. With pooled data, CK practice collected most the flower heads in levels 1–5, 94.29% in total, while T practice had most flower heads in levels 2–5, a total of 90.50%. As a result, under the conditions of this experiment, compared with the traditional human labor management practice, the agricultural drone management practice may produce flower heads with larger sizes and fresh weights.

Key words: Agricultural unmanned vehicle, Agricultural drone, UAV, Organic broccoli, Production.

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研究報告

Acibenzolar-S-methyl 防治柑橘潰瘍病之效果及其誘導抗病機制之探討

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摘要

林靜宜、林慧如。2022。Acibenzolar-S-methyl 防治柑橘潰瘍病之效果及其誘導抗病機制之探討。台灣農業研究 71(4):309–319。

由 *Xanthomonas citri* subsp. *citri* 所引起的柑橘潰瘍病為目前世界柑橘生產栽培最具經濟重要性的細菌性病害，銅劑為當前廣泛應用於防治柑桔潰瘍病之藥劑，但過度或長期使用容易誘發病原菌產生抗銅性。本研究調查雲林及嘉義地區之柑橘潰瘍病菌株對銅劑的感受性，於篩選之菌株中發現 2 株抗銅菌株及 46 株耐銅菌株。由於抗銅菌株可導致銅劑防治失效，有鑑於此，開發其他可施用並符合永續農業理念之防治方法有其必要性。本研究利用 acibenzolar-S-methyl (ASM)、4-4 式波爾多液 (Bor) 及兩者同時配合使用 (ASM + Bor)，於溫室條件下進行對柑橘潰瘍病之防治效果評估。種植於盆栽之檸檬幼苗每株分別以土壤澆灌 5 mg a.i. ASM、葉面施用 4-4 式波爾多液或兩者配合同時施用，於處理後 3 d 進行柑橘潰瘍病菌接種。結果顯示 3 種處理之罹病度分別為 19.14%、15.0% 及 15.4%，與無處理之對照組 (39.96%) 具有顯著差異。進一步分析抗病相關酵素活性，結果發現單獨以 ASM 處理之植株，其過氧化物酶 (peroxidase; POD) 及過氧化氫酶 (catalase; CAT) 之活性明顯增加。由以上結果可知，ASM 可有效降低植株對潰瘍病之罹病度，能藉由提高 POD 與 CAT 活性以誘導檸檬植株產生抗性而達到防治效果。

關鍵詞：阿拉酸式苯 -S- 甲基、柑橘、潰瘍病。

前言

柑橘為芸香科 (Rutaceae) 多年生果樹，栽培種類繁多，是世界上產量最大的果樹產業，亦是台灣重要的經濟果樹之一，根據 2020 年行政院農業委員會 (農委會) 資料統計 (https://agrstat.coa.gov.tw/sdweb/public/book/Book.aspx)，台灣栽種面積超過 25,000 ha，年產量超過 52 萬公噸，以椪柑、柳橙、文旦柚、桶柑及檸檬等為常見的栽培品種，其中椪柑、柳橙的栽培面積最大，皆超過 5,000 ha。影響柑橘生產之病蟲害種類繁多，台灣有紀錄的柑橘病害即達百餘種 (Tzeng 2019)，其中由 *Xanthomonas citri* subsp. *citri* 引起之柑橘潰瘍病 (citrus canker) 為限制柑橘栽培生產的重要細菌性病害，植株的葉片、果實及枝條皆可受病原菌感染，形成褐色木栓化之病斑，除了造成柑橘落葉、落果導致嚴重減產與降低果品品質外，同時也為果實外銷時重要的檢疫病害。

長期以來國內的柑橘生產者廣泛地使用銅劑以減少柑橘潰瘍病引起之危害，然而銅劑常導致土壤中累積過多的銅，進而產生毒害並影響環境生態系 (Alva *et al*. 1995)。此外，長期使用銅劑會大幅增加病原菌族群產生抗銅菌株之風險 (Behlau *et al*. 2012b)，導致銅劑之防治效果降低甚至失效。柑橘潰瘍病菌之抗銅菌株最早於 1990 年代於阿根廷的柑桔苗圃中被發現 (Behlau *et al*. 2011)，隨後法屬留尼旺島

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(Reunion) 及馬提尼克島 (Martiniaure) 等地也陸續出現抗銅菌株 (Richard *et al*. 2017)，近來的研究文獻也顯示台灣栽培果園中亦已出現柑橘潰瘍病菌的抗銅菌株 (Lai *et al*. 2021)。目前國內柑橘潰瘍病使用之推薦防治用藥，除了銅劑之外，還有抗生素類藥劑，但於使用上亦有抗藥菌株之生成及影響人體健康與環境生態的潛在風險。有鑑於此，開發其他可施用並符合永續農業理念之防治方法有其必要性。

後天性系統抗性 (systemic acquired resistance; SAR) 為植物藉外來因子誘導啟動之植物體全身性的防禦反應，此抗病性通常具有持久性及廣泛性 (An & Mou 2011; Fu & Dong 2013)，其中水楊酸 (salicylic acid; SA) 被認為扮演重要的訊息傳遞角色 (Zhang *et al*. 2010)。其誘導因子可為生物性之病原菌，亦可為非生物性之化學物質如水楊酸、苯併噻二唑 (benzothiadiazole) 及其衍生物等 (Gorlach *et al*. 1996)。阿拉酸式苯-S-甲基 (acibenzolar-S-methyl; ASM) 為苯併噻二唑的衍生物，可透過植物體內的水楊酸訊號傳遞路徑，誘導植物產生防禦反應，以其作為誘導植物抗病性的商品已於歐美地區販售，並廣泛應用於防治多種由真菌、細菌、病毒及線蟲等引起的作物病害 (Cole 1999; Oostendorp *et al*. 2001; Chinnasri *et al*. 2006)。目前國內的相關研究則有應用於防治不結球白菜炭疽病與苗立枯病 (Hsu 2011)，但尚無應用於木本作物上之研究。因此，本研究之目的為 ASM 應用在柑橘上，於溫室進行對柑橘潰瘍病防治之藥效試驗，同時探討其誘導抗病之可能機制。

材料與方法

柑橘潰瘍病菌菌株收集

本試驗利用 2010–2019 年之間自嘉義及雲林地區的柑橘園罹病葉片上分離及純化的柑橘潰瘍病菌菌株作為供試菌株 (表 1)。採集之罹病柑橘葉片洗淨瀝乾後，切取病健部組織，經 0.5% 次氯酸鈉 (NaOCl) 及 70% 酒精表面消毒各 30 s，再以無菌水漂洗 3 次後，將組織切碎置入無菌水中震盪均勻，利用畫線平板方式

表 1. 柑橘潰瘍病菌菌株於含銅培養基上之生長情形。

Table 1. The growth of the *Xanthomonas citri* subsp. *citri* (strains) collected from Yunlin and Chiayi of Taiwan and their sensitivity to copper on mannitol glutamate yeast (MGY) medium.

				Concentration of Cu amended to MGY medium (mg L^{-1})							
Location	Year	Total strain number	Growth conditions[z]	0	50	100	150	175	200	300	400
Yunlin	2019	16	Regular growth	16	16	16	16	14	-	-	-
			Weak growth	-	-	-	-	2	-	-	-
Chiayi	2010	7	Regular growth	7	7	7	7	2	2	2	2
			Weak growth	-	-	-	-	-	-	-	-
	2014	2	Regular growth	2	2	2	2	-	-	-	-
			Weak growth	-	-	-	-	-	-	-	-
	2017	3	Regular growth	3	3	3	3	-	-	-	-
			Weak growth	-	-	-	-	-	-	-	-
	2018	9	Regular growth	9	9	9	5	1	-	-	-
			Weak growth	-	-	-	4	-	-	-	-
	2019	43	Regular growth	43	43	43	43	25	-	-	-
			Weak growth	-	-	-	-	4	-	-	-
Total		80	Regular growth	80	80	80	76	42	2	2	2
			Weak growth	-	-	-	4	6	-	-	-

[z] Regular growth indicates a homogenous and thorough coverage of the spot where the bacterial suspension was deposited; weak growth indicates that some growth was observed but not as uniform or strong as the reference (bacterial growth of each strain on medium without copper).

將細菌懸浮液塗於 NA (nutrient agar) (Difco Laboratories; Becton, Dickinson and Company, Franklin Lakes, NJ, USA) 平板上，於 27℃定溫箱中培養 3 d 後，挑選單一菌落至新 NA 培養基培養純化。純化後之分離株經分子鑑定及病原性確認為 *Xanthomonas citri* subsp. *citri* (Xcc) 後，保存於甘油中以供日後試驗使用。

菌株對銅之感受性分析

將保存之柑橘潰瘍病菌株 (表 1) 於 NA 平板上活化後，利用無菌水配製細菌懸浮液 [濃度約 10^8 colony-forming unit (CFU)mL^{-1}]，取 10 µL 細菌懸浮液點放至含有硫酸銅 ($CuSO_4$·$5H_2O$, Sigma-Aldrich, St. Louis, MO, USA) 之 MGY 培養基 (mannitol glutamate yeast medium) (Behlau *et al*. 2012a) 上進行銅感受性分析，平板含硫酸銅之濃度分別為 0、50、100、150、175、200、300 及 400 mg L^{-1}。將培養皿置於 27℃之定溫箱中生長 3 d 後，記錄菌株生長情形。每濃度處理 3 皿，3 重複，本試驗重複進行 2 次。依據菌株生長情形分為：正常生長 (regular growth)，指點放至培養基上的細菌懸浮液可生長並完整覆蓋點放之圓點；微弱生長 (weak growth)，指點放至培養基上的細菌懸浮液可生長但與對照組 (無添加銅之培養基) 相較之下，生長較為微弱 (Marin *et al*. 2019)。

抗銅基因分子檢測

將可生長於銅濃度 150–400 mg L^{-1} 培養基之菌株進行抗銅基因分子檢測。參考 Wang *et al*. (1993) 之方法並修改後進行核酸萃取，沾取培養於 NA 上之菌株放入 50 µL 之 0.5 N NaOH，劇烈震盪後短暫離心，再加入 150 µL 之 1M Tris-HCl (pH 8.0) 混合均勻，取 10 µL 加入無菌水稀釋 10×，以此製備液 1 µL 作為模板。利用以抗銅基因 (copper resistance genes) 序列片段設計的專一性引子對 copLF/copLR、copAF/copAR 及 copBF/copBR (Behlau *et al*. 2013) 進行聚合酵素連鎖反應 (polymerase chain reaction; PCR)，經電泳分析後以確認菌株基因體中是否具有抗銅基因序列。

ASM 配製與 4-4 式波爾多液 (4-4 Bordeaux mixture) 之製備

取 5 mg ASM (acibenzolar-S-methyl, PESTANAL®, Sigma-Aldrich, St. Louis, MO, USA) 溶入 300 mL 無菌水中，即為每株試驗株之施用量，完成配製後於當日施用。4-4 式波爾多液 (1 L 含有 4 g 硫酸銅與 4 g 生石灰)，將所需水量等分為兩桶，分別溶解等重量之硫酸銅 (購於聯合農業資材行，台灣嘉義縣) 與生石灰 (購於聯合農業資材行，台灣嘉義縣)，再將硫酸銅溶液緩緩倒入石灰水中，並於倒入過程中不停攪拌以利兩者充分混合，亦於完成配製後當日施用。

ASM 防治柑橘潰瘍病之溫室試驗評估

本試驗選用四季檸檬 (*Citrus limon*) 作為供試植物，自園藝資材行購得約 2 年生幼株，種植於塑膠盆 (直徑 24 cm，高 29 cm)，並置於溫室中。接種用菌株 (Xcc1954) 為本研究中之嘉義分離株，耐銅劑之特性菌株，可生長於銅濃度 150–175 mg L^{-1} 培養基。試驗用之接種源製備法如下：將保存之 Xcc1954 培養於 NA 培養基，於 27℃經 2 d 培養後，以無菌水洗出成為細菌懸浮液，調整菌量濃度約為 10^8 CFU mL^{-1} 即為接種源。防治效果評估試驗分為下列 4 組，(1) 試驗組為利用土壤澆灌方式施用 1 次 ASM (每株 5 mg a.i.)；另以不同作用機制之銅劑單獨使用及配合 ASM 同時使用之處理作為比較組，分別為 (2) 葉面施用 4-4 式波爾多液 1 次；(3) 同時利用土壤澆灌 ASM (每株 5 mg a.i.) 及葉片噴灑 4-4 式波爾多液；(4) 未處理藥劑之植株作為對照組。於藥劑處理 3 d 後以人工接種柑橘潰瘍病菌，每處理 3 株植株，每株植株選擇 5 枝新梢 (每枝條至少有 5 片新葉)，接種後的植株於溫室中定期觀察其發病情形及記錄其罹病等級。病害指數 (disease index) 分為 8 級：0 級為無病徵、1 級為葉片出現 1–3 個病斑、3 級為葉片出現 4–10 個病斑、5 級為葉片出現 11–20 個病斑及 7 級為葉片出現 > 20 個病斑 (Shiotani *et al*. 2008)，再依下列公式計算罹病度 (disease severity)。

罹病度 (%) = Σ (指數 × 該指數罹病葉數)/ (7 × 總調查葉數) × 100%

酵素活性測定

植株分別於接種後第 0、2、4、8 及 11 d，取接種枝條上之第 6–8 葉約 0.1 g 之葉片組織，並保存於 -20℃冰箱。酵素分析每樣本為 3 重複，試驗重複 2 次。

(1) 過氧化氫酶 (catalase, CAT)：依 Kato & Shimizu (1987) 方法進行，以液態氮研磨樣本後，加入 1 mL sodium phosphate buffer (50 mM, pH 6.8) 均勻震盪，於 4℃冷凍離心機離心 20 min；取 0.2 mL 上清液，加入 2.7 mL sodium phosphate buffer (100 mM, pH 7.0) 與 0.1 mL H_2O_2 (1 M)，混合均勻後，以分光光度計於 240 nm 測量吸光值 1 min，記錄 0 s 與 60 s 之讀值，酵素活性單位 (unit) 為每分鐘消耗 1 μM H_2O_2。另以 Bradford (1976) 蛋白定量法，測量粗萃取液之總蛋白含量，計算每毫克蛋白質的酵素活性。

(2) 過氧化物酶 (peroxidase, POD)：參考 Hsieh (2010) 之方法，將樣本以液態氮研磨後加入 1 mL potassium phosphate buffer (50 mM, pH 5.8，內含 0.8 M KCl) 均勻震盪，置 4℃冷凍離心機離心 20 min，取上清液至新的 1.5 mL 離心管中。將酵素粗萃取液、potassium phosphate buffer (50 mM, pH 5.8)、guaiacol (21.6 mM) 及 H_2O_2 (39 mM) 以 1 : 10 : 10 : 9 的比例均勻混合後，以分光光度計於 470 nm 測量吸光值 1 min，記錄 0 s 與 60 s 之讀值，酵素活性單位為每分鐘產生 1 μM tetraguaiacol。另以 Bradford (1976) 蛋白定量法，測量粗萃取液中總蛋白含量，計算每毫克蛋白質的酵素活性。

(3) 超氧化物歧化酶 (superoxide dismutase; SOD)：依修正之 Deepak *et al*. (2006) 之方法，將樣本以液態氮研磨後，加入 1 mL sodium phosphate buffer (50 mM, pH 7.0) 均勻震盪，置 4℃冷凍離心機離心 20 min，取上清液至新的 1.5 mL 離心管中。再取 100 μL 酵素粗萃取液加入 100 μL 反應液 A [150 mM sodium phosphate buffer, 39 mM methionine, 0.3 mM EDTA, 225 μM nitro blue tetrazolium (NBT), pH 7.8]、30 μL 20 μM riboflavin，最後以無菌水加至 300 μL，以分光光度計於 570 nm 測量吸光值 10 min，記錄 0 s 與 600 s 之讀值，酵素活性單位為抑制 50% NBT 之吸光值變化。另以 Bradford (1976) 蛋白定量法，測量粗萃取液中總蛋白含量，計算每毫克蛋白質的酵素活性。

ASM 對柑橘潰瘍病菌生長抑制能力之影響

採用濾紙圓盤法進行 ASM 對柑橘潰瘍病菌 (Xcc1954) 之抑制能力評估，將直徑 0.8 cm 之濾紙圓盤 (TOYO ADVANTEC, Tokyo, Japan) 分別置於 0、100、200、300 及 400 mg L^{-1} 之 ASM 中，於室溫下浸漬 10 min 後將濾紙圓盤取出陰乾，再放置於已塗布有 0.1 mL 細菌懸浮液 (濃度約為 10^8 CFU mL^{-1}) 之 NA 平板上 (直徑 9 cm)，每一培養平板放 2 個濾紙圓盤，並以無菌水處理之濾紙圓盤作為對照組。將各處理之培養平板放置於 27℃無光照定溫箱內，培養 2 d 後，取出測量抑制圈大小。每處理 3 重複，試驗重複 2 次。

統計分析

試驗資料利用 SAS 9.1 版統計分析軟體先進行變方分析 (analysis of variance; ANOVA)，再以最小顯著性差異 (Fisher's least significant difference; LSD) 測驗在 5% 顯著水準下，比較處理間平均值之差異。

結果

柑橘潰瘍病菌株對銅之感受性分析及抗銅基因分子檢測

本研究於 2010–2019 年間分離保存之柑橘潰瘍病菌株總計 80 株，其中雲林地區為 16 株，嘉義地區為 64 株 (表 1)。將菌株分別於含有不同濃度硫酸銅之 MGY 培養基上進行銅濃度之感受性分析，結果顯示所有供試菌株 (80 株) 皆可於銅濃度 0–100 mg L^{-1} 之培養基上正常生長。培養基含銅濃度為 150 mg L^{-1} 時，95.0%

(76 株) 的菌株皆可正常生長，其中 5.0% (4 株) 的菌株生長與無添加銅之培養基上生長之菌落比較則較為微弱，如 2018 年收集之嘉義分離株 Xcc1808 (圖 1A)。當培養基含銅濃度為 175 mg L^{-1} 時，7.5% (6 株) 的菌株可微弱生長，52.5% (42 株) 的菌株可正常生長，如 2019 年收集之嘉義分離株 Xcc1954 (圖 1A)。培養基含銅濃度為 200–400 mg L^{-1} 時，僅餘 2 株 2010 年自嘉義地區分離之菌株 (Xcc1004 與 Xcc1023) 可正常生長 (圖 1A)。

進一步將可生長於銅濃度 150–400 mg L^{-1} 培養基之 80 株菌株，利用抗銅基因專一性引子對 (包括 *copL*、*copA* 與 *copB*) 進行基因片段增幅 (Behlau *et al*. 2013)，結果發現可生長於含銅濃度 200–400 mg L^{-1} 培養基的 2 株嘉義分離株 Xcc1004 與 Xcc1023 可增幅出預期條帶，分別是 *copL* 基因片段 356 bp (base pair), *copA* 基因片段為 870 bp 及 *copB* 基因片段為 531 bp，其他菌株如雲林分離株 Xcc1942 與嘉義分離株 Xcc1954、Xcc1808 等則未測得預期條帶 (圖 1B)。

ASM 防治柑橘潰瘍病之溫室試驗評估

本研究利用 ASM 作為主要試驗之防治資材，與 4-4 式波爾多液同時配合使用及單獨使用銅劑之效果進行評估。結果發現於接種 3 wk 後，施用 ASM 之處理組植株罹病度為 19.14%、同時使用 4-4 式波爾多液與 ASM 之

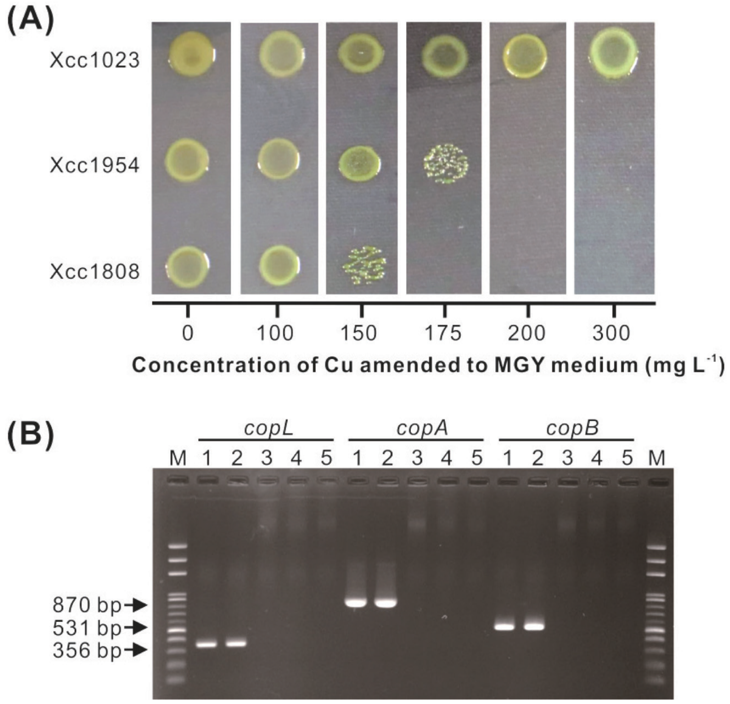

圖 1. 柑橘潰瘍病菌株於含銅培養基上之感受性分析及抗銅基因分子檢測。(A) 抗銅菌株 Xcc1023、耐銅菌株 Xcc1954 與 Xcc1808 於添加不同銅濃度的培養基上之生長情形。(B) 利用聚合酵素連鎖反應 (polymerase chain reaction; PCR) 檢測抗銅基因 (*copL*: 356 bp、*copA*: 870 bp 及 *copB*: 531 bp) 片段。行 M：1 kb DNA ladder；行 1、2：抗銅菌株 Xcc1004 及 Xcc1023；行 3、4、5：耐銅菌株 Xcc1942、Xcc1954 及 Xcc1808。

Fig. 1. Sensitivity to copper on mannitol glutamate yeast (MGY) medium and detection of copper resistant genes from the *Xanthomonas citri* subsp. *citri* strains. (A) Growth of copper resistant strain Xcc1023, copper tolerant strains Xcc1954 and Xcc1808 on MGY medium supplemented with different concentrations of copper. (B) PCR amplification of copper resistance gene fragments of *copL* (356 bp), *copA* (870 bp) and *copB* (531 bp) from *Xanthomonas citri* subsp. *citri* strains. Lane M: 1 kb DNA ladder; lanes 1 and 2, copper resistant strain Xcc1004 and Xcc1023; lanes 3, 4 and 5, copper tolerant strains Xcc1942, Xcc1954 and Xcc1808.

處理組為 15.4%，僅使用 4-4 式波爾多液時之罹病度為 15.0%，對照組植株罹病度則為 39.96%，前述三種處理皆與對照組之罹病度具有顯著差異，但三者之間則無顯著差異 (圖 2)。

酵素活性測定

試驗植株於使用 ASM 或 4-4 式波爾多液處理後 3 d 進行病原菌接種，並於接種後第 0、2、4、8、11 d 分別測定 CAT、POD 及 SOD 之酵素活性。測定結果顯示，CAT 活性於單獨使用 ASM 之處理組，發現於接種後即大幅增加，至第 2 天到達最高峰，於第 2–11 天期間逐漸降低，但於此測定期間之 CAT 活性皆明顯高於其他處理組及接種對照組 0.95–0.3 倍；同時使用 ASM 與 4-4 式波爾多液之處理組與接種對照組呈現相似的活性變化趨勢，於接種後小幅上升，至第 2 天達到最高，之後小幅下降並呈現穩定的趨勢，且兩者之間的 CAT 活性並無顯著差異；單獨使用 4-4 式波爾多液處理組於接種後之酵素活性亦呈上升趨勢，於第 4 天達最高，但其活性與對照組並無明顯差異，之後呈小幅下降的趨勢 (圖 3A)。而 POD 活性測定結果發現，單獨以 ASM 處理之實驗組，其酵素活性於接種後 4 d 內緩慢地增加，第 4 天後增加幅度加大，於第 8 天達最高峰，此時之 POD 活性高於同時間之對照組 0.2 倍，之後活性呈現降低趨勢，但於第 11 天時之酵素活性仍高於對照組 0.3 倍；使用 4-4 式波爾多液之處理組與接種對照組亦呈現相似的活性變化趨勢，於第 8 天酵素活性達最高峰，其中 4-4 式波爾多液之處理組此時之 POD 活性低於對照組 0.13 倍；而同時使用 ASM 與 4-4 式波爾多液之處理組酵素活性於接種後 2 d 內小幅增加，之後於第 2–11 天期間活性呈現平穩的現象，但於接種後第 4 天前之酵素活性高於其他處理組 (圖 3B)。SOD 活性測定結果顯示所有處理組與對照組之趨勢相似，活性於接種後 2 d 內大幅度增加，隨後逐漸降低，第 8–11 天則呈增加的趨勢，但各處理組與接種對照組並無顯著差異 (圖 3C)。

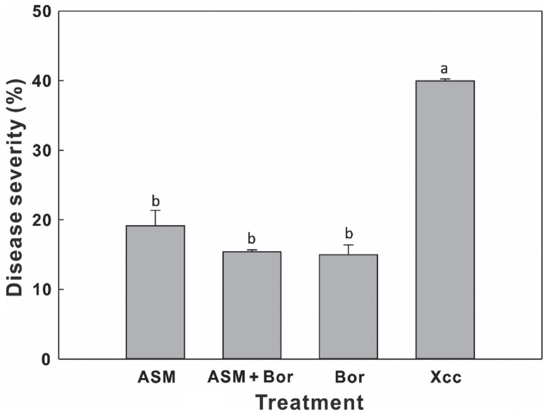

圖 2. 檸檬植株以 acibenzolar-S-methyl (ASM)、4-4 式波爾多液 (Bor) 及兩者同時配合使用 (ASM + Bor) 處理 3 d 後，再接種柑橘潰瘍病菌 (Xcc)，經 3 wk 後之發病情形。

Fig. 2. Effects of acibenzolar-S-methyl (ASM), 4-4 bordeaux mixture (Bor) and the combination of ASM + Bor on the disease severity of citrus canker 3 d prior to the inoculation of *Xanthomonas citri* subsp. *citri* (Xcc) on lemon plants and evaluated after 3 wk of inoculation. Bars indicated the standard deviation. Values with the same letter are not significantly different according to Fisher's least significant difference (LSD) test (P = 0.05).

ASM 對柑橘潰瘍病菌生長抑制能力之影響

利用濾紙圓盤法進行培養基上之抑制能力試驗，結果發現以 0、100、200、300 及 400 mg L^{-1} 之 ASM 處理之濾紙圓盤周圍皆無抑制圈之形成 (data not show)，潰瘍病菌 (Xcc1954) 正常生長，由此可知，ASM 對潰瘍病菌無直接毒殺效果。

討論

銅劑為目前廣泛應用於防治柑橘潰瘍病之藥劑，長期使用下容易誘發病原菌產生抗銅性，進而降低銅劑之防治效果，然而柑橘潰瘍病菌之抗銅菌株於阿根廷首次發現後 (Behlau *et al*. 2011)，已陸續於其他柑橘產區發現抗銅菌株 (Richard *et al*. 2017; Lai *et al*. 2021)。本研究調查雲林及嘉義地區之柑橘潰瘍病菌株發現，多數可忍受之最高銅濃度為 150–175 mg L^{-1}，僅 2 株分離自嘉義地區的菌株 (Xcc1004 及 Xcc1023) 可於含銅濃度為 400 mg L^{-1} 之培養基上生長。依據 Marin *et al*. (2019) 研究報告

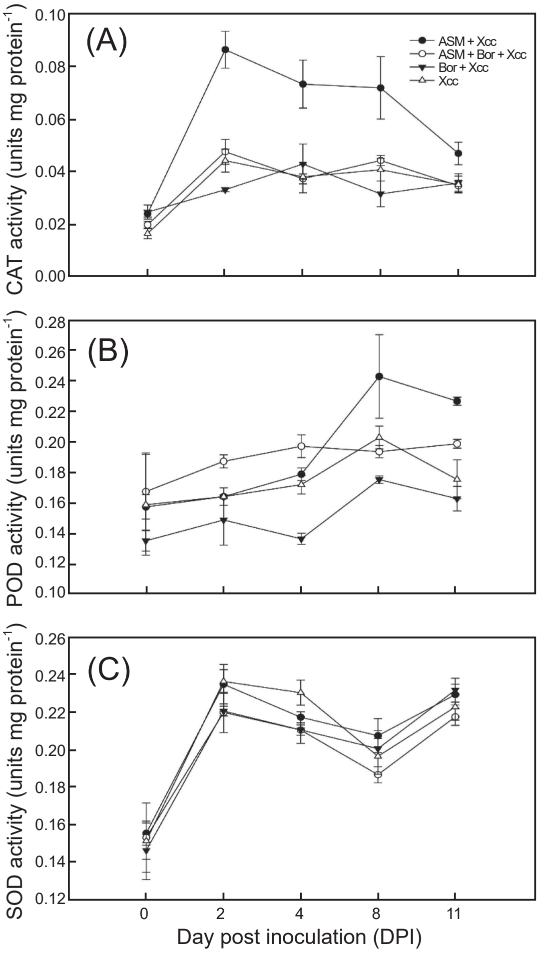

圖 3. 植株接種柑橘潰瘍病菌後 0–11 d 內 (A) 過氧化氫酶 (CAT)、(B) 過氧化物酶 (POD) 及 (C) 超氧化物歧化酶 (SOD) 之活性變化。

Fig. 3. (A) Activity of catalase (CAT), (B) peroxidase (POD) and (C) superoxide dismutase (SOD) in lemon leaves from plants with different treatments: (●) drenched with acibenzolar-S-methyl and inoculated with *Xanthomonas citri* subsp. *citri* (ASM + Xcc), (○) drenched with acibenzolar-S-methyl, sprayed 4-4 bordeaux mixture and inoculated with *Xanthomonas citri* subsp *citri* (ASM + Bor + Xcc). (▼) sprayed 4-4 bordeaux mixture and inoculated with *Xanthomonas citri* subsp. *citri* (Bor + Xcc). (△) inoculated with *Xanthomonas citri* subsp. *citri* (Xcc, untreated control). Enzyme activities were evaluated at 0, 2, 4, 8 and 11 d after inoculation. Bars indicated the standard deviation.

中將柑橘潰瘍病菌株對銅感受性之分類，可分為 3 種，分別是敏感菌株 (sensitive strain, Cu^S) (< 150 mg L^{-1})、耐性菌株 (tolerant strain, Cu^T) (150–200 mg L^{-1}) 及抗性菌株 (resistant strain, Cu^R) (> 200 mg L^{-1})，若以上述分類作為標準，顯示本研究中之雲嘉地區菌株多數可歸類為耐性菌株，其中 2 株嘉義菌株則可歸類為抗性菌株。此外，前人研究發現於 *Xanthomonas* spp. 的抗銅菌株中具有 *cop* 基因組 (如 *copA*、*copB* 及 *copL*) 存在 (Behlau *et al*. 2011)，本研究中篩選出之 2 株抗銅菌株 (Xcc1004 及 Xcc1023) 亦測得 *copA*、*copB* 及 *copL* 存在，證實此 2 株嘉義菌株具抗銅性。近年之文獻亦指出台灣之柑橘潰瘍病的抗銅菌株已於台中神岡及嘉義地區發現 (Lai *et al*. 2021)，綜上所述，台灣主要的柑橘產區已出現抗銅性菌株，且分離自雲嘉地區的多數菌株已對銅產生耐性。有鑑於此，本研究利用 ASM 作為防治資材，評估應用於柑橘潰瘍病之防治效果有其必要性。

ASM 為苯併噻二唑的衍生物，被殺菌劑抗藥性行動委員會 (Fungicide Resistance Action Committee; FRAC) 歸類為殺菌劑，但本身並不具殺菌的效果，而是透過植物體內的水楊酸訊號傳遞路徑，誘導植物產生防禦反應 (Oostendorp *et al*. 2001)。本研究結果顯示柑橘潰瘍病菌於高濃度 400 mg L^{-1} ASM 下也能正常生長，由此可知，ASM 對潰瘍病菌並無直接毒殺效果。目前 ASM 已被證實可誘導多種植物產生抗病反應，防治由不同病原菌引起之病害，如日本梨黑星病 (Faize *et al*. 2004)、胡瓜炭疽病 (Cool & Ishii 2002)、番茄青枯病 (Pradhanang *et al*. 2005) 等，於柑橘潰瘍病的防治應用方面，則於枳柚 (Francis *et al*. 2009)、葡萄柚 (Graham & Myers 2011) 及墨西哥萊姆 (Ibrahim *et al*. 2017) 等柑橘作物上證實具有防治的效果，且結果顯示利用土壤澆灌方式較葉片施用法的防治效果更為明顯 (Graham & Myers 2011)。本研究之溫室試驗結果亦顯示於接種前 3 d 以土壤澆灌方式施用 1 次 ASM，可有效降低檸檬發生柑橘潰瘍病之罹病度，且與施用 4-4 式波爾多液之防治效果無顯著差異。進一步分析與抗病相關酵素之關聯性，結果發現接種後於 ASM 處理組葉片內之 POD 與 CAT 之活性明顯增加，POD 活性於接種後 4–8 d 明顯增加，於第 8 天達到高峰；CAT 活性則於接種後即明顯增加，於第 2 天達到高峰；SOD 活性亦於接種後即明

顯增加，於第 2 天達到高峰，然而與接種之對照組無明顯差異。相似之結果也於 Al-Saleh *et al*. (2015) 之研究中發現墨西哥萊姆葉面施用水楊酸，於接種後 1–3 d 內 POD 與 CAT 之活性明顯增加，並於接種後 3–5 d 內達高峰。目前已有相關研究指出，於日本梨 (Faize *et al*. 2004)、胡瓜 (Cools & Ishii 2002) 及番茄 (Soylu *et al*. 2003) 等多種作物內之 POD 活性均可被 ASM 誘導活化，而 POD 可藉由與過氧化氫反應以刺激木質素形成，同時亦降低過氧化氫對植物細胞的氧化傷害 (Thatcher *et al*. 2005)。由此可知，POD 於 ASM 誘導產生之防禦反應中扮演重要的角色。而在感染過程中抗氧化酵素成員中的 SOD 與 CAT 於接種後初期之活性增加，顯示檸檬受柑橘潰瘍病菌感染後會產生大量活性氧化分子 (reactive oxygen species; ROS) 來參與對抗病原菌，其中 AMS 誘導對 CAT 活性影響顯著。參與木質素合成作為抗病機制的 POD 在病原菌感染過程中，其活性隨著感染時間的延長逐漸增加。以上結果顯示，AMS 誘導檸檬產生抗性的可能機制為初期 CAT 活性可快速增加，POD 活性為主要抗病反應，而 SOD 活性則不受 AMS 影響。然而，還有其他可能之抗病反應如 pathogenesis-related (PR) proteins 與總酚化物等於防禦反應中扮演的角色，則有待進一步探討。此外，本研究發現 AMS 與 4-4 式波爾多液一起配合使用時其防治效果與單獨使用時比較並無特別差異之處，且分析酵素活性之結果中，僅 POD 活性於接種後初期 (0–4 d 內) 較其他處理組高。相似的結果也於 AMS 與氫氧化銅一起配合使用之試驗中發現 (Graham & Leite 2004)，惟原因仍需進一步研究探討，因此 AMS 於使用上不建議與銅劑同時使用。

柑橘潰瘍病為影響台灣柑橘生產栽培之重要細菌性病害，銅劑為國內生產者經常使用的防治方法，長期且高頻率的使用銅劑，易造成病原菌對藥劑產生抗藥性，同時也衍生出消費者對農藥殘留及食品安全的顧慮。本研究調查發現嘉義地區已出現柑橘潰瘍病的抗銅菌株，因此，增加可利用並符合永續農業理念之防治藥劑或資材有其必要性。本研究初步證實以土壤澆灌方式施用 ASM，於溫室試驗中可有效降低檸檬發生柑橘潰瘍病之罹病度，且與施用 4-4 式波爾多液之防治效果無顯著差異。其提供抗性之機制是藉由提高 POD 與 CAT 之活性以誘導檸檬植株產生抗性而達到防治效果。未來可進一步評估於田間施用之劑量、頻率等使用條件及對柑橘植株生長之影響，以提供更有效、安全之使用方法。

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Efficacy of Acibenzolar-S-methyl and Its Induced Resistance Mechanism in Controlling Citrus Canker

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Abstract

Lin, C. Y. and H. J. Lin. 2022. Efficacy of acibenzolar-S-methyl and its induced resistance mechanism in controlling citrus canker. J. Taiwan Agric. Res. 71(4):309–319.

Citrus canker caused by *Xanthomonas citri* subsp. *citri* (Xcc) is one of the most economically important bacterial disease in the international citrus industry. The copper-based bactericides were widely use to or control citrus canker. However, frequent applications of copper-based bactericides induce the development of bacterial strains either resistant or tolerant to copper. In this study, Xcc strains were collected from citrus orchards in Yunlin and Chiayi of Taiwan and used to assess the sensitivity to copper on a solid medium. The tests identified two copper resistant strains and 46 copper tolerant strains. Copper resistance in plant pathogenic bacteria contributes to a failure to control plant bacterial diseases by copper bactericides. In view of this, it is necessary to develop alternative control methods for sustainable agricultural practices. In this study, the individual and combined effects of acibenzolar-S-methyl (ASM) and 4-4 bordeaux mixture (Bor) were investigated in a greenhouse to control citrus canker disease. Three treatments were conducted on potted lemon (*Citrus limon*) seedlings: soil drench with 5 mg a.i. ASM, foliar spray with Bor, and a combination of the above two treatments (ASM + Bor). The lemon seedlings were inoculated with Xcc 3 d post treatments. The results showed that the disease severities of ASM, Bor and ASM + Bor were 19.14%, 15.0%, and 15.4%, respectively, which were significantly different from the untreated control (39.96%). For the defence-related enzyme activity assay, progressive increases in peroxidase and catalase activities were found in lemon seedlings treated with ASM alone. Our results suggested that ASM was effective in reducing canker disease severity, mainly through enhancing the activities of peroxidase and catalase *in planta*.

Key words: Acibenzolar-S-methyl, Citrus, Citrus canker.

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研究報告

慣行與永續農法對水稻田瓢蟲之影響

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摘要

本研究呈現 2014–2020 年於嘉義縣溪口農場及雲林縣雲林分場農業試驗田區，調查不同農耕下田區之瓢蟲種類及數量之結果。於溪口農場及雲林分場黃色黏板分別調查到 11 種及 12 種瓢蟲，其中六條瓢蟲是數量最多之瓢蟲，分別占所調查到瓢蟲數量之 83.1% 及 79.2%。慣行農耕及永續農耕田區調查到瓢蟲數量及種類數沒有差異。水稻田與落花生田調查到瓢蟲數量與種類數並無差異，但二期作落花生田調查到瓢蟲種類顯著少於一期作水稻田。溪口農場慣行農耕及永續農耕田區比較，噴施殺蟲劑明顯降低農友操作田區瓢蟲種類及數量。本試驗結果顯示，六條瓢蟲於慣行農耕、永續農耕及農友操作田區，均是最優勢的捕食性天敵，這項資訊有助於未來研究人員發展水稻害蟲生物防治策略，降低農民對化學農藥的依賴，但是在此之前應避免隨意使用化學農藥，以利保育六條瓢蟲這些重要的捕食性天敵。

關鍵詞：水稻田、慣行農耕、永續農耕、瓢蟲、長期生態研究。

前言

水稻 (*Oryza sativa* Linnaeus) 是世界上重要糧食作物之一，全世界有超過 50% 人口以稻米作為每日所需要熱量主要來源 (Counce *et al*. 2000; Maclean *et al*. 2002; Coats 2003)。研究顯示部分瓢蟲種類是水稻田重要害蟲天敵 (Rekha *et al*. 2009; Shanker *et al*. 2013a) 主要捕食蚜蟲。Shanker *et al*. (2018b) 於室內研究試驗中，以褐飛蝨 (*Nilaparvata lugens* Stal)、白背飛蝨 (*Sogatella furcifera* Hovarth) 及綠葉蟬 (*Nephotettix* spp.) 等重要水稻害蟲之三齡若蟲測試，發現八條瓢蟲 (*Harmonia octomaculata* Fabricius)、六條瓢蟲 (*Cheilomenes sexmaculata* Fabricius)、波紋瓢蟲 (*Coccinella transversalis* Fabricius) 及橙瓢蟲 (*Micraspis discolor* Fabricius) 之成蟲及三齡幼蟲皆有取食行為。

捕食者在害蟲管理上的生態角色往往被低估，但目前研究顯示捕食者在農業生態系中，在調節害蟲族群功能上扮演重要的角色，藉由管理捕食者的族群數量與豐度，有可能大幅降低害蟲的族群數量 (Symondson *et al*. 2002; Shanker *et al*. 2018a)。蚜蟲、粉蝨、薊馬、介殼蟲、飛蝨、葉蟬及蟎類等是農作物重要小型害蟲，由於世代短、繁殖率高，容易族群爆發對作物造成嚴重危害，捕食性瓢蟲於自然界中常伴隨上述這些害蟲並調節其族群發展 (Omkar & Harsur 2020)。前人研究在水稻生態環境中的瓢蟲如橙瓢蟲 (*M. discolor* Fabricius) 等時常發生的捕食者，有助於壓制水稻田害蟲族群密度 (Rekha *et al*. 2009; Shanker *et al*. 2013a)。

水稻田瓢蟲族群易受農田操作模式影響，特別是噴施化學藥劑，Anitha *et al*. (2020) 於印度水稻田調查研究結果，橙瓢蟲隸屬之兼

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食瓢蟲屬 (*Micraspis*) 瓢蟲於有機農耕水稻田平均調查數量為 32.41 隻，於無處理水稻田為 30.48 隻，而農友慣行操作水稻田則為 16.10 隻，顯示瓢蟲族群多寡顯著受農民操作方式影響。為明瞭台灣地區水稻田發生瓢蟲種類及不同操作下對瓢蟲影響，2014–2020 年間於嘉義縣溪口農場及雲林縣雲林分場進行，調查不同耕作制度下對水稻田發生瓢蟲種類、數量及影響。

材料與方法

本試驗分別於行政院農業委員會農業試驗所嘉義分所溪口農場 (23°34'N, 120°24'E, 8.0 ha) 及台南區農業改良場雲林分場 (23°37'58.5"N, 120°28'34.3"E, 7.0 ha) 農業試驗田區，依照農業試驗所之長期生態農業調查研究操作手冊 (https://lter.tari.gov.tw/) 進行慣行農耕 (conventional agroecosystem; CA) 與永續農耕 (sustainable agroecosystem; SA) 田區之瓢蟲調查試驗，試驗田區包括雙期作水田 (水稻「台南 11 號」) 及水旱輪作田 (落花生「台南 14 號」)。慣行農耕蟲害管理方法為不定期檢視田間害蟲發生情形，並根據現況擬訂防治藥劑種類及施藥適期，於水稻栽培期間發生重要害蟲如飛蝨及縱捲葉蟲時，綜合考量各害蟲發生情形，全期最多施藥 1 次。肥料管理一期作：氮肥 150–180 kg ha^{-1}，磷肥 (P_2O_5) 及鉀肥 (K_2O) 依肥力診斷推薦施用；二期作：氮肥 125–160 kg ha^{-1}，磷肥 (P_2O_5) 及鉀肥 (K_2O) 依肥力診斷推薦施用。蟲害管理部分，永續農耕為原則上不施任何藥劑防治害蟲，但害蟲發生嚴重，可能造成無產量收成之虞時，即以慣行農耕害蟲管理方法，進行施藥防治，全期最多施藥 1 次。肥料管理部分，則以當地的氣候條件為基礎，並參考前作之殘留土壤的養分量及前季或歷年的產量紀錄資料，利用模式估計並配合營養診斷技術及節約措施，調整生長期的施肥量。農友操作田區，蟲害管理方法為於水稻一期作期間平均共施用蟲害防治藥劑 3–4 次，二期作期間則平均施用水稻蟲害防治藥劑 4–5 次。

於 2014–2020 年間進行瓢蟲種類調查，慣行農耕與永續農耕田區瓢蟲調查，方法為選定 3 塊慣行農耕田，面積總計為 1.51 ha，及 3 塊永續農耕田，面積總計為 1.52 ha，每一試驗田各設立 2 支 T 型支架 (T 型支架橫桿長 120 cm、距離地面高度為 150 cm)，每個支架設立於試驗田中間前、後兩邊，距離田埂 20 m 處，支架上懸掛 1 張黃色黏板 (33 cm × 28 cm)，上述資材均購自振詠興業 (台灣台中市)。每 2 星期將黃色黏板收回並掛上新黏板，並參考 Yao & Tao (1972) 及 Yu & Wang (1999) 之檢索與圖鑑，於實驗室內檢視並記錄黏板上所捕獲瓢蟲的種類與數量。水田及旱田之田區瓢蟲調查，方法為選定 3 塊水稻田及 3 塊落花生田，調查方式同上。農藥對瓢蟲影響調查試驗為於 2017–2018 年，一期水稻種植時期，分別選定 3 塊溪口農場慣行農耕田 (未施用殺蟲劑)、永續農耕田 (未施用殺蟲劑) 及農友操作田區進行瓢蟲種類及數量調查，調查方法同上。

試驗所得各項資料，慣行農耕、永續農耕與農友操作田區每片黃色黏板平均瓢蟲種類及數量比較；溪口農場及雲林分場調查，每片黃色黏板瓢蟲平均數量比較等資料先以 SAS-EG (Version 7.1) 統計分析軟體，進行變方分析 (analysis of variance; ANOVA) 後，再以最小顯著差異性測驗 (least significant difference test; LSD test) 分析其差異顯著性。慣行農耕及永續農耕調查，每片黃色黏板瓢蟲平均數瓢蟲種類及數量、水稻田及落花生田調查每片黃色黏板平均瓢蟲種類及數量等資料，則以 *t*-test 分析平均值間是否存在差異。

結果

2014–2020 年於溪口農場及雲林分場以黃色黏板分別調查到 11 種及 12 種瓢蟲，分別是六條瓢蟲 [*C. sexmaculata* (Fabricius)]、六星瓢蟲 [*Oenopia formosana* (Miyatake)]、七星瓢蟲 (*Coccinella septempunctata* Linnaeus)、龜紋瓢蟲 [*Propylaea japonica* (Thunberg)]、橙瓢蟲 [*M. discolor* (Fabricius)]、錨紋瓢蟲 [*Lemnia biplagiata* (Swartz)]、波紋瓢蟲 (*C. transversalis* Fabricius)、赤星瓢蟲 [*Lemnia saucia* (Mulsant)]、八條瓢蟲 [*H. octomacu-

lata (Fabricius)]、大 13 星瓢蟲 [*Synonycha grandis* (Thunberg)]、孟氏隱唇瓢蟲 (*Cryptolaemus montrouzieri* Mulsant) 及柯氏素菌瓢蟲 (*Illeis koebelei* Timberlake)，其中溪口農場於 2014–2020 年未調查到孟氏隱唇瓢蟲 (表 1)。

2014–2020 年於溪口農場慣行農耕及永續農耕，一期水稻田、二期水稻田及二期落花生田調查到瓢蟲數量沒有差異 (表 2)。雲林分場慣行農耕及永續農耕，一期水稻田、二期水稻田及二期落花生田調查到瓢蟲數量亦沒有差異

表 1. 2014–2020 年溪口農場及雲林分場瓢蟲種類。

Table 1. Species of lady beetles of Sikou farm and YuinLin branch station from 2014–2020.

	Mean number of lady beetle (Mean ± SE)[z]	
Species/location	Sikou farm	YuinLin branch farm
Cheilomenes sexmaculata	2.13 ± 0.24 a	1.92 ± 0.35 a
Oenopia formosana	0.01 ± 0.00 c	0.01 ± 0.00 de
Coccinella septempunctata	0.02 ± 0.01 c	0.01 ± 0.00 de
Propylaea japonica	0.02 ± 0.01 c	0.01 ± 0.00 de
Micraspis discolor	0.18 ± 0.07 b	0.02 ± 0.01 de
Lemnia biplagiata	0.10 ± 0.04 b	0.04 ± 0.01 cd
Coccinella transversalis	0.01 ± 0.01 c	0.02 ± 0.01 de
Lemnia saucia	0.07 ± 0.01 c	0.16 ± 0.04 b
Harmonia octomaculata	0.01 ± 0.01 c	0.02 ± 0.01 de
Synonycha grandis	0.01 ± 0.00 c	0.02 ± 0.01 de
Cryptolaemus montrouzieri	0.00 ± 0.00 c	0.01 ± 0.00 e
Illeis koebelei	0.13 ± 0.03 b	0.08 ± 0.02 bc

[z] For each column, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

表 2. 2014–2020 年溪口農場慣行農耕與永續農耕田區瓢蟲數量。

Table 2. Number of lady beetles of Sikou farm in conventional agriculture (CA) and sustainable agriculture (SA) fields from 2014–2020.

	Mean number of lady beetle (Mean ± SE)[z]					
	First crop season paddy		Second crop season paddy		Second crop season peanut	
Species/period	CA	SA	CA	SA	CA	SA
Cheilomenes sexmaculata	2.51 ± 0.24	2.25 ± 0.23	2.18 ± 0.70	1.73 ± 0.50	1.94 ± 0.62	1.99 ± 0.58
Oenopia formosana	0.02 ± 0.01	0.01 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Coccinella septempunctata	0.02 ± 0.01	0.01 ± 0.00	0.01 ± 0.01	0.03 ± 0.02	0.02 ± 0.01	0.02 ± 0.01
Propylaea japonica	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.03	0.01 ± 0.01	0.00 ± 0.00
Micraspis discolor	0.31 ± 0.11	0.37 ± 0.19	0.06 ± 0.03	0.02 ± 0.01	0.04 ± 0.03	0.00 ± 0.00
Lemnia biplagiata	0.13 ± 0.05	0.10 ± 0.03	0.10 ± 0.06	0.10 ± 0.05	0.00 ± 0.00	0.01 ± 0.01
Coccinella transversalis	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.03	0.02 ± 0.01
Lemnia saucia	0.08 ± 0.01	0.08 ± 0.03	0.04 ± 0.02	0.04 ± 0.01	0.02 ± 0.01	0.00 ± 0.00
Harmonia octomaculata	0.01 ± 0.01	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00
Synonycha grandis	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Cryptolaemus montrouzieri	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Illeis koebelei	0.24 ± 0.05	0.20 ± 0.05	0.03 ± 0.01	0.02 ± 0.01	0.02 ± 0.02	0.02 ± 0.01

[z] For each row, the asterisk indicates a significant difference from the control at $P < 0.05$ (t-test).

(表 3)。溪口農場及雲林分場慣行農耕及永續農耕，一期水稻田、二期水稻田及二期落花生田調查到瓢蟲種類數均無差異 (表 4)。

2014–2020 年於溪口農場二期水稻及落花生田調查到瓢蟲數量沒有顯著差異，一期水稻田調查到之橙瓢蟲及柯氏素菌瓢蟲發生數量顯著多於二期水稻田，其餘瓢蟲數量無差異。溪口農場一期水稻田調查到之六星瓢蟲、橙瓢蟲、錨紋瓢蟲、赤星瓢蟲及柯氏素菌瓢蟲顯著多於二期落花生田 (表 5)。

2014–2020 年於雲林分場二期水稻及落花生田調查到瓢蟲數量亦沒有顯著差異。雲林分場一期水稻田調查到之柯氏素菌瓢蟲發生數量顯著多於二期水稻田及二期落花生田，其餘瓢蟲數量均無顯著差異 (表 6)。

2014–2020 年於溪口農場二期水稻及落花生田調查到瓢蟲種類無顯著差異。溪口農場一期水稻田與二期水稻田調查到瓢蟲種類數無差異，一期水稻田調查到瓢蟲種類數顯著高於二期落花生田。雲林分場二期水稻及落花生田調查到瓢蟲種類數無顯著差異，雲林分場一期水稻田調查到瓢蟲種類顯著高於二期落花生田 (表 7)。

2017–2018 年一期水稻，農友操作田區調查到六條瓢蟲數量、橙瓢蟲數量及瓢蟲種類均顯著少於溪口農場慣行農耕區及永續農耕區 (表 8、表 9)。

表 3. 2014–2020 年雲林分場慣行農耕與永續農耕田區瓢蟲數量。

Table 3. Number of lady beetles of YuinLin branch station in conventional agriculture (CA) and sustainable agriculture (SA) fields from 2014–2020.

	Mean number of lady beetle (Mean ± SE)[z]					
	First crop season paddy		Second crop season paddy		Second crop season peanut	
Species/period	CA	SA	CA	SA	CA	SA
Cheilomenes sexmaculata	1.56 ± 0.23	1.23 ± 0.17	1.60 ± 0.26	1.34 ± 0.23	3.61 ± 1.85	2.55 ± 1.11
Oenopia formosana	0.01 ± 0.01	0.03 ± 0.02	0.01 ± 0.01	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01
Coccinella septempunctata	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00
Propylaea japonica	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01
Micraspis discolor	0.02 ± 0.02	0.02 ± 0.01	0.00 ± 0.00	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
Lemnia biplagiata	0.07 ± 0.02	0.03 ± 0.00	0.02 ± 0.01	0.04 ± 0.02	0.03 ± 0.01	0.02 ± 0.02
Coccinella transversalis	0.03 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.02	0.02 ± 0.02	0.01 ± 0.01
Lemnia saucia	0.24 ± 0.07	0.20 ± 0.06	0.20 ± 0.07	0.11 ± 0.04	0.10 ± 0.04	0.10 ± 0.06
Harmonia octomaculata	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.02
Synonycha grandis	0.03 ± 0.02	0.02 ± 0.01	0.02 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01
Cryptolaemus montrouzieri	0.01 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Illeis koebelei	0.20 ± 0.06	0.10 ± 0.05	0.02 ± 0.01	0.01 ± 0.00	0.02 ± 0.01	0.01 ± 0.01

[z] For each row of crop season, the asterisk indicates a significant difference from the control at $P < 0.05$ (t-test).

表 4. 2014–2020 年溪口農場與雲林分場慣行農耕與永續農耕田區瓢蟲種類數。

Table 4. Lady beetle species number of Sikou farm and YuinLin branch station in conventional agriculture (CA) and sustainable agriculture (SA) fields from 2014–2020.

	Mean lady beetle species (Mean ± SE)[z]					
	First crop season paddy		Second crop season paddy		Second crop season peanut	
Location/period	CA	SA	CA	SA	CA	SA
Sikou farm	6.71 ± 0.36	6.43 ± 0.53	5.00 ± 0.76	4.29 ± 0.68	2.86 ± 0.63	2.43 ± 0.30
YuinLin branch station	7.43 ± 0.75	6.71 ± 0.42	4.43 ± 0.69	4.00 ± 0.44	3.71 ± 0.18	3.86 ± 0.46

[z] For each row, the asterisk indicates a significant difference from the control at $P < 0.05$ (t-test).

表 5. 2014–2020 年溪口農場水田與旱田田區瓢蟲數量。

Table 5. Number of lady beetles of Sikou farm in lowland and upland fields from 2014–2020.

	Mean number of lady beetle (Mean ± SE)[z]					
	Second crop season		First crop season	Second crop season	First crop season	Second crop season
Species/period	Lowland	Upland	Lowland	Lowland	Lowland	Upland
Cheilomenes sexmaculata	1.96 ± 0.59	1.96 ± 0.60	2.28 ± 0.17	1.96 ± 0.59	2.28 ± 0.17	1.96 ± 0.60
Oenopia formosana	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.01	0.00 ± 0.00	0.02 ± 0.01[y]	0.00 ± 0.00
Coccinella septempunctata	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01
Propylaea japonica	0.02 ± 0.02	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.02	0.02 ± 0.01	0.01 ± 0.01
Micraspis discolor	0.04 ± 0.02	0.02 ± 0.01	0.30 ± 0.13[y]	0.03 ± 0.02	0.30 ± 0.13[y]	0.02 ± 0.01
Lemnia biplagiata	0.10 ± 0.05	0.01 ± 0.00	0.13 ± 0.05	0.10 ± 0.05	0.13 ± 0.05[y]	0.01 ± 0.00
Coccinella transversalis	0.01 ± 0.01	0.02 ± 0.02	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.02
Lemnia saucia	0.04 ± 0.01	0.01 ± 0.01	0.11 ± 0.02	0.04 ± 0.01	0.11 ± 0.02[y]	0.01 ± 0.01
Harmonia octomaculata	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.01	0.00 ± 0.00
Synonycha grandis	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00
Cryptolaemus montrouzieri	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Illeis koebelei	0.03 ± 0.01	0.02 ± 0.01	0.22 ± 0.05[y]	0.03 ± 0.01	0.22 ± 0.05[y]	0.02 ± 0.01

[z] Mean numbers captured per yellow sticky paper.
[y] A significant difference from the control at $P < 0.05$ (*t*-test).

表 6. 2014–2020 年雲林分場水田與旱田田區瓢蟲數量。

Table 6. Number of lady beetles of YuinLin branch station in lowland and upland fields from 2014–2020.

	Mean number of lady beetle (Mean ± SE)[z]					
	Second crop season		First crop season	Second crop season	First crop season	Second crop season
Species/period	Lowland	Upland	Lowland	Lowland	Lowland	Upland
Cheilomenes sexmaculata	1.50 ± 0.23	3.08 ± 1.47	1.52 ± 0.18	1.50 ± 0.23	1.52 ± 0.18	3.08 ± 1.47
Oenopia formosana	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.01
Coccinella septempunctata	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.01	0.01 ± 0.00	0.02 ± 0.01	0.01 ± 0.00
Propylaea japonica	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01
Micraspis discolor	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.01
Lemnia biplagiata	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.03 ± 0.01
Coccinella transversalis	0.02 ± 0.02	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.02	0.02 ± 0.01	0.01 ± 0.01
Lemnia saucia	0.17 ± 0.06	0.10 ± 0.04	0.19 ± 0.04	0.17 ± 0.06	0.19 ± 0.04	0.10 ± 0.04
Harmonia octomaculata	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01
Synonycha grandis	0.01 ± 0.01	0.00 ± 0.00	0.03 ± 0.02	0.01 ± 0.01	0.03 ± 0.02	0.00 ± 0.00
Cryptolaemus montrouzieri	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Illeis koebelei	0.01 ± 0.01	0.02 ± 0.01	0.16 ± 0.02[y]	0.01 ± 0.01	0.16 ± 0.02[y]	0.02 ± 0.01

[z] Mean numbers captured per yellow sticky paper.
[y] A significant difference from the control at $P < 0.05$ (*t*-test).

表 7. 2014–2020 年溪口農場與雲林分場水田與旱田田區瓢蟲種類數。

Table 7. Lady beetle species number of Sikou farm and YuinLin branch station in lowland and upland fields from 2014–2020.

	Mean lady beetle species (Mean ± SE)[z]					
	Second crop season		First crop season	Second crop season	First crop season	Second crop season
Location/period	Lowland	Upland	Lowland	Lowland	Lowland	Upland
Sikou farm	5.71 ± 0.92	3.71 ± 0.64	7.29 ± 0.57	5.71 ± 0.92	7.29 ± 0.57[y]	3.71 ± 0.64
YuinLin branch station	5.57 ± 0.57	4.71 ± 0.29	7.36 ± 0.63	5.57 ± 0.57	7.36 ± 0.63[y]	4.71 ± 0.29

[z] Mean numbers captured per yellow sticky paper.
[y] A significant difference from the control at $P < 0.05$ (*t*-test).

表 8. 溪口農場慣行農耕、永續農耕及農友操作 2017–2018 年之一期作水稻田瓢蟲數量。

Table 8. Number of lady beetles r of Sikou farm conventional agriculture (CA), sustainable agriculture (SA) and farmer practiced treatment in first crop season paddy from 2017–2018.

	Mean number of lady beetle (Mean ± SE)[z]		
Species/treatment	CA	SA	Farmer practiced
Cheilomenes sexmaculata	2.82 ± 0.38 a	2.64 ± 0.65 a	1.50 ± 0.09 b
Oenopia formosana	0.00 ± 0.00 a	0.01 ± 0.01 a	0.00 ± 0.00 a
Coccinella septempunctata	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a
Propylaea japonica	0.02 ± 0.02 a	0.00 ± 0.00 a	0.00 ± 0.00 a
Micraspis discolor	0.68 ± 0.24 a	0.92 ± 0.25 a	0.00 ± 0.00 b
Lemnia biplagiata	0.09 ± 0.02 a	0.05 ± 0.02 a	0.11 ± 0.02 a
Coccinella transversalis	0.01 ± 0.01 a	0.00 ± 0.00 a	0.00 ± 0.00 a
Lemnia saucia	0.04 ± 0.02 a	0.03 ± 0.02 a	0.02 ± 0.02 a
Harmonia octomaculata	0.00 ± 0.00 a	0.01 ± 0.01 a	0.00 ± 0.00 a
Synonycha grandis	0.01 ± 0.01 a	0.01 ± 0.01 a	0.00 ± 0.00 a
Cryptolaemus montrouzieri	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a
Illeis koebelei	0.32 ± 0.18 a	0.19 ± 0.12 a	0.14 ± 0.05 a

[z] For each row, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

表 9. 溪口農場慣行農耕、永續農耕及農友操作 2017–2018 年之一期作水稻田瓢蟲種類數。

Table 9. Species number of lady beetles of Sikou farm conventional agriculture (CA), sustainable agriculture (SA) and farmer practiced treatment in first crop season paddy from 2017–2018.

Treatment	Mean lady beetle species (Mean ± SE)[z]
CA	6.25 ± 0.49 a
SA	5.50 ± 0.65 a
Farmer practiced	3.25 ± 0.25 b

[z] Means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

討論

Sharma *et al*. (2017) 於印度希馬喬邦 (Joshimath) 調查研究中指出，六條瓢蟲是希馬喬邦中優勢瓢蟲之一，廣布於亞溫帶區、亞熱帶區、乾燥溫帶區及濕溫帶區等不同農業氣候區中幾乎所有的農作生產系統中。本研究 2014–2020 年於嘉義縣溪口農場及雲林縣雲林分場調查結果，六條瓢蟲亦為最優勢瓢蟲，分別占 2014–2020 年所調查到瓢蟲數量之 83.1% 及 79.2% (表 1)，溪口農場次優勢瓢蟲為橙瓢蟲、柯氏素菌瓢蟲及錨紋瓢蟲。雲林分場次優

勢瓢蟲為赤星瓢蟲及柯氏素菌瓢蟲，顯示出地區差異性。

研究指出六條瓢蟲可捕食螺旋粉蝨 (*Aleurodicus dispersus* Russell)、吹綿介殼蟲 (*Icerya purchasi* Maskell)、柑桔木蝨 (*Diaphorina citri* Kuwayama)、桑木蝨 (*Paurocephala psylloptera* Grawford) 及稻麥蚜 [*Acyrthosiphon pisum* (Harris)] 等 60 種蚜蟲 (Chen *et al*. 2009)。Biwash *et al*. (2019) 於印度西孟加拉省農業及園藝作物生態系中調查瓢蟲種類多樣性，六條瓢蟲於水稻田中主要捕食白翅褐脈葉蟬 [*Cofana spectra* (Distant)]。Shanker *et al*. (2018b) 於室內研究顯示六條瓢蟲成蟲每日可捕食 2.35–4.60 隻褐飛蝨 [*Nilaparvata lugens* (Stal)] 及 3.12–3.87 隻白背飛蝨 [*Sogatella furcifera* (Hovarth)]，三齡幼蟲每日可捕食 1.16 隻褐飛蝨及 2.40 隻白背飛蝨。上述結果顯示六條瓢蟲是水稻及農業害蟲重要天敵，採取適度保育六條瓢蟲等捕食性天敵措施，有助於壓制水稻田害蟲族群 (Kundoo & Khan 2017; Karenina *et al*. 2019)。

肥料是作物生長系統中與土壤品質有關之重要因子，進而影響作物生長及害蟲族群 (Rowen *et al*. 2019)。研究顯示化學肥料促進作物生長，且使作物本身之植體特性利於害蟲生長發育，增加的害蟲族群提升對天敵吸引 (Garratt *et al*. 2010; Duchovskienė *et al*. 2012)。惟本試驗 2014–2020 年於溪口農場及雲林分場調查結果顯示，六條瓢蟲及其餘瓢蟲的種類及數量，於慣行農耕及永續農耕田區間並無顯著差異 (表 2–4)。確切原因目前尚未明瞭，推測可能為溪口農場及雲林分場慣行農耕及永續農耕田區，肥料使用差別並未對作物及害蟲發生產生顯著影響。

瓢蟲可分為窄幅分布種類及可適應極寬廣或極端的環境條件的種類，其中特定作物型態會吸引特定瓢蟲，表現出瓢蟲於不同季節對棲所偏好，尤其微氣候是影響瓢蟲棲所偏好的重要因子 (Iperti 1999; Zahoor *et al*. 2003)。本試驗 2014–2020 年於溪口農場及雲林分場調查結果顯示，比較二期作水田及旱田間瓢蟲發生的數量及種類數均無差異，顯示於當期作雖因作物種類不同 (水稻及落花生) 並未顯著影響瓢蟲發生種類及數量；於不同期作間，柯氏素菌瓢蟲調查數量於溪口農場及雲林分場一期作均顯著高於二期作，顯示出季節差異性；橙瓢蟲調查數量於溪口農場一期農田作均顯著高於二期作，六星瓢蟲、錨紋瓢蟲及赤星瓢蟲調查數量於溪口農場一期作水稻田數量顯著高於二期作落花生田數量，惟在雲林分場，上述瓢蟲於不同期作及作物間數量並無差異，顯示出地區不同差異 (表 5–7)。

溪口農場及雲林分場二期作水田調查到瓢蟲數量少於一期作水田，二期作落花生田瓢蟲數量更顯著少於一期作水田，二期作瓢蟲種類較少有可能會影響對害蟲生物防治效果。前人研究顯示，於小範圍田區中增加植物多樣性，低強度的雜草管理，有助於提高捕食者對植食性害蟲的壓制效果 (Shanker *et al*. 2013b; Dassou & Tixier 2016)。許多雜草已知可作為瓢蟲棲息處所，於其中瓢蟲產卵、取食花粉、花蜜及替代食餌 (Kranz *et al*. 2002)，作為保育生物防治措施，利用這些雜草可以增加田區瓢蟲數量 (Wäckers & van Rijn 2012)。藉由上述保育生物防治措施，維持田區自然發生天敵族群，可有效防止害蟲族群爆發，同時減少殺蟲劑使用及降低其對環境傷害 (Boreau de Roincé *et al*. 2012)。

研究顯示不同的田間操作明顯影響瓢蟲族群，特別是農藥使用，在防治害蟲同時也殺死瓢蟲。Sharanappa *et al*. (2019) 於印度 Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS) 農業研究試驗田研究顯示，噴施化學農藥明顯降低水稻田中瓢蟲數量，與未施藥對照區 (1.32 隻瓢蟲/株水稻) 相比，有機磷藥劑 (monocrotophos) 處理區瓢蟲數量僅有 0.63 隻/株水稻。Ngin *et al*. (2017) 於柬埔寨水稻田研究亦顯示，隨著用藥次數增加，水稻田捕食性天敵數量愈減少，水稻田施用藥劑次數 3 次及 4 次，瓢蟲等捕食性天敵數量顯著少於施用藥劑 1 次及 2 次之水稻田。本試驗於 2017–2018 年，比較溪口農場未施用化學農藥之一期作永續農耕及慣行農耕水稻田與農友操作水稻田瓢蟲數量及種類，結果亦顯示農友操作水稻田調查到平均瓢蟲種類、

六條瓢蟲及橙瓢蟲數量 (3.25, 1.50, 0.00) 均顯著少於溪口農場永續農耕水稻田 (6.25, 2.64, 0.92) 及慣行農耕水稻田 (5.50, 2.82, 0.68) (表 8、表 9)，顯示噴施農藥對水稻田發生瓢蟲數量及種類造成嚴重影響。

本研究提出了嘉義及雲林地區水稻田瓢蟲種類清單，並顯示六條瓢蟲是數量最多的捕食性瓢蟲天敵，這研究為將來的工作人員提供了有用的訊息，可以為制定該地區作物蟲害生物強化行動管理策略，亦有助於減少農民對化學農藥的依賴。本研究未來也將對六條瓢蟲進行進一步的生物生態學研究。但是在此之前應避免隨意使用化學農藥來保育六條瓢蟲這些重要的捕食性天敵。

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Effects of Conventional and Sustainable Farming Practices on Lady Beetles in Paddy Fields

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Hsu, P. C., Y. J. Dong, Y. H. Yang, C. L. Chen, and H. T. Shih. 2022. Effects of conventional and sustainable farming practices on lady beetles in paddy fields. J. Taiwan Agric. Res. 71(4):321–330.

A field survey was conducted during 2014–2020 for lady beetles in different types of farming fields in Chiayi County Sikou farm and Yunlin County YuinLin branch Station. Results showed that 11 and 12 lady beetles were captured with yellow sticky paper in Sikou farm and YuinLin branch Station, respectively. Among lady beetles, *Cheilomenes sexmaculata* (Fabricius) was the most dominant lady beetle in all types of framing fields, occupying 83.1% and 79.2% of the total lady beetle number separately. There was no difference in lady beetle species and quantity between conventional and sustainable agroecosystem fields and also between second crop season lowland paddy and upland groundnut fields. Significantly fewer lady beetle species in second crop season upland fields than first crop season paddy. Insecticide application significantly reduced lady beetle species and quantity in farmer-practiced fields compared with no chemical-treated conventional agriculture and sustainable agriculture fields in Sikou farm. The results of our tests showed that *C. sexmaculata* was the most dominant lady beetle in different types of farming fields. This study presents useful information for future workers to develop biological control strategies for paddy pests, which will be useful in reducing the farmers' dependence on harmful chemical pesticides. However, there is a need to conserve *C. sexmaculata* these important beetles by avoiding the indiscriminate use of chemical pesticides.

Key words: Paddy, Conventional agroecosystem, Sustainable agroecosystem, Lady beetle, Long-term ecological research.

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研究報告

台灣香菇段木上炭角菌之鑑定與藥劑感受性試驗

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余祥萱、呂昀陞。2022。台灣香菇段木上炭角菌之鑑定與藥劑感受性試驗。台灣農業研究 71(4):331–341。

摘要

台灣段木香菇年平均產量約為 264 Mg，占香菇市場的 0.6%，栽植地區主要分布於宜蘭縣、桃園市、新竹縣、苗栗縣、南投縣及屏東縣等山區原鄉社區。段木上常見之微生物多屬於木材腐朽菌，此些微生物造成段木香菇產量與品質之影響甚少研究。然而，近年來由於農業委員會林下經濟政策之推動，使段木香菇栽種面積增加，因而段木香菇栽培過程中之病蟲害問題也漸受重視。本研究自嘉義縣阿里山鄉栽植香菇之段木上，進行炭角菌之採集與分離，經田間子實體外觀比較和 internal transcribed spacer (ITS) 序列分析後，初步鑑定為 *Xylaria* 屬之真菌。以平板進行對峙培養試驗得知，炭角菌和香菇之菌絲接觸時，香菇菌絲除生長受影響外，更出現弱化之情形，再經 2 wk 培養，炭角菌菌絲甚至包覆香菇菌絲繼續生長，顯現所分離之炭角菌可對香菇菌絲造成危害。進一步以 60% 腐絕水懸劑進行藥劑試驗，結果顯示炭角菌於含 30 ppm 腐絕之 potato dextrose agar (PDA) 培養基和稀釋 1,000× 腐絕 [60% suspension concentrates (SC)] 之濾紙圓片處理組中其生長皆受抑制，顯示此藥劑具有可作為防治炭角菌之化學藥劑的潛力。本研究為台灣首篇探討炭角菌影響台灣段木香菇生產之報導，未來也將持續調查國內各段木香菇產區的炭角菌發生情形，以作為擬定香菇段木上炭角菌防治策略之參考依據。

關鍵詞：炭角菌、段木香菇、林下經濟、腐絕。

前言

美味多元的菇類，為餐桌上常見的珍饌，是國人攝取豐富蛋白質、維生素、礦物質及膳食纖維等營養素之重要來源，更是世界各國料理不可或缺的食材之一。目前台灣菇類產值已達 130 億元新台幣，占整體蔬菜產值 18%，為蔬菜產業重要之一環 (Shih *et al*. 2019)。台灣菇類栽培之歷史可溯源自 1909 年，至今已超過百年歷史，其中菇類生產的模式可分成三類，分別為段木栽培、木屑栽培及堆肥栽培。以段木栽植香菇為最早的栽培模式，於 1983 年達國內發展高峰，後續則因 1970 年代中期開發出太空包栽培技術與段木取得不易等原因，造成段木生產模式逐漸沒落 (Huang *et al*. 1988)。但近年來由於觀光產業的盛行，加上段木所栽植出的香菇不管是香氣和口感皆比太空包香菇更為獨特，因此少數原住民部落或客家族群仍持續栽植。目前台灣段木香菇產量約 264 Mg，占香菇產量的 0.6%，栽植戶數約有 160 戶，主要分布於宜蘭縣南澳和大同鄉、桃園市復興區、新竹縣關西鎮、苗栗縣南庄鄉、南投縣埔里鎮與信義鄉及屏東縣大武鄉等地，合計每年約有 1 萬噸段木之栽培量 (Hung 2019)。

台灣屬於亞熱帶氣候，高溫多濕的環境容易衍生病蟲害問題，菇類生產過程中也不例外。目前已知危害香菇之真菌有綠黴菌 (*Trichoderma harzianum*、*Trichoderma koningii*、*Trichoderma pleuroticola*、*Trichoderma pseudokoningii*、*Trichoderma polysporum*、*Trichoderma viride*)、紅麵包黴菌 (*Neurospora*

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spp.)、白黴菌 (*Cladobotryum* varium)、青黴菌 (*Penicillium* spp.)、黃麴菌 (*Aspergillus* spp.)、放線菌 (*Actinomyces* spp.) 等 (Liao 1985; Miyazaki 2018; Gea *et al*. 2021)；而在段木香菇栽培上常見的有害真菌更包含炭團菌 (*Hypoxylon* sp.)、髮網菌 (*Stemonitis* sp.)、裂褶菌 (*Schizophyllum* sp.)、炭角菌 (*Xylaria* sp.)、多孔菌 (*Polyporus* sp.)、肉座菌 (*Hypocrea schweinitzii*、*Hypocrea lactea*、*Hypocrea peltata*) 和綿腐病菌 (*Hypomyces pseudocorticiicola*) (Okuda *et al*. 2016; Miyazaki 2018) 等木材腐朽菌；細菌則有腐敗病菌 (*Ewingella americana*) (Arima *et al*. 2010)、褐變腐敗病菌 (*Pseudomonas fluorescens*)、黑腐病菌 (*Pseudomonas tolaasii*) (Miyazaki 2018) 等；害蟲則大部分以白蟻、甲蟲等昆蟲為主 (Okabe 2006)。過去國內並未針對段木上有害菌類與昆蟲造成段木香菇產量與品質之影響進行詳細研究。行政院農業委員會於 2016 年起為達山林永續經營之效益，開始推動林下經濟 (under-forest economy) 政策，此概念於美國、中國及日本等國已行之有年，主要希望透過林地下優良的環境條件栽培高經濟價值作物，創造農林永續經營的生產模式，以提升森林的附加價值 (Hou *et al*. 2017)。經過多方的討論和評估後，目前台灣已容許在林業用地之森林冠層下合法經營「森林蜂產品」、「金線連」及「段木香菇、木耳」等 3 項森林副產物，鼓勵林農在不傷害林地的情形下進行栽植生產，以取得短期收入，此舉使段木香菇栽種面積逐年增加，因而段木香菇栽培過程中之病蟲害問題也開始備受重視。

段木栽培過程中所遭遇的有害真菌大部分屬於木材腐朽菌，經初步調查後發現炭角菌 (*Xylaria* sp.) 常發生於段木香菇栽培過程中，且出現炭角菌之段木產量有明顯下降之情況，顯示炭角菌可能為影響段木香菇產量不良的因子之一。炭角菌屬於真菌界 (Fungi)、子囊菌門 (Ascomycota)、糞殼菌綱 (Sordariomycetes)、炭角菌目 (Xylariales)、炭角菌科 (Xylariaceae) 之真菌，全世界已被記載者有 100 餘種，主要生長於腐爛的樹樁或木頭上，如：山毛櫸 (*Fagus*)、楓樹 (*Acer*) 和橡樹 (*Quercus*) 等皆為其寄主 (Robinson & Laks 2010)。該菌菌絲無色透明，分支具 90° 直角且有隔膜 (Cañón *et al*. 2019)；子實體型態為高度約 5–7 cm 的棒狀或叢枝狀，又俗稱為「死者手指」(dead man's fingers) (Hacioglu *et al*. 2011)，其子實體不似其他菇類具有肉質質地，較偏向木質化，因此並不適合食用，且部分物種可和白蟻巢共生，具有醫藥用價值 (Wangsawat *et al*. 2021)。此外，炭角菌屬於白腐菌，可分泌木質分解酵素自木頭中取得自身生長所需的養分，導致木材腐朽 (Liers *et al*. 2006)，而目前國內對於炭角菌與段木香菇間之交互關係瞭解甚少，也無相關研究報導。因此，本研究將以嘉義縣阿里山鄉栽植香菇的段木上著生之炭角菌進行分離與分類鑑定，並釐清炭角菌對香菇菌絲生長之影響，最後測試 60% 腐絕水懸劑是否具有抑菌潛力，以提供未來擬定相關防治方法之重要參考依據。

材料與方法

炭角菌採集、分離及保存

2021 年 11 月間於嘉義縣阿里山鄉達邦村之段木香菇園進行炭角菌採集，採得之子實體樣品置於夾鏈袋中保濕，於室溫下送回實驗室進行組織分離。將採集之子實體以無菌水進行表面清洗後，利用滅菌過之解剖刀切取子實體的內部組織，並以馬鈴薯葡萄糖培養基 (potato dextrose agar; PDA. Becton Dickinson and Company, Franklin Lakes, NJ, USA) 進行純化培養，靜置於 25℃之恆溫箱中。7 d 後待菌絲長出，以 5 mm 打孔器切取較完整的菌落邊緣，並再次以 PDA 培養基進行繼代培養。在 25℃下培養 7–10 d，並同步觀察菌落生長速度與菌絲狀態，挑選生長勢良好且菌落圓整的菌株 CYX-1 作為後續試驗菌株，並切取所挑選菌株之菌絲塊，以 1% 海藻醣保存於 4℃中。於實驗前，將供試菌株自保存管中取出，再以 PDA 培養基進行活化，待 7–14 d 後即可進行後續試驗。

炭角菌之鑑定

將在 PDA 培養基生長 7 d 之炭角菌 CYX-1

的菌絲進行基因組 DNA 萃取。以真菌核醣體內部轉錄間隔 (internal transcribed spacer; ITS) 作為鑑定序列，使用正向引子 ITSa (GGAAGGAGAAGTCGTAACAAGG) 和反向引子 ITSb (CTTTTCCTCCGCTTATTGATATG) 進行聚合酶鏈鎖反應 (polymerase chain reaction; PCR) (Blattner 1999)。增幅反應過程為以 94℃進行初次的 DNA 解旋反應 (denature) 2 min；進入增幅循環後，以 94℃進行 DNA 解旋反應 30 s，以 54℃進行 DNA 黏合反應 (annealing) 20 s，72℃進行 DNA 延長反應 (extension) 60 s，循環過程重複 33 個循環；72℃進行 DNA 最終延長反應 5 min；最後將 PCR 產物委由基龍米克斯生物科技股份有限公司 (Genomics Biotech Inc., New Taipei, Taiwan) 進行純化和定序。得到的序列資料再與 National Center for Biotechnology Information (NCBI) 網站中之基因資料庫進行序列分析比對。

炭角菌與香菇之交互關係

為瞭解炭角菌對香菇菌絲生長之影響，將自阿里山鄉所分離之炭角菌菌株 CYX-1 和香菇菌株 Br-1 進行 PDA 與木屑平板之對峙培養，本研究之供試香菇菌株 Br-1 係由行政院農業委員會農業試驗所植物病理組菇類研究室所提供。木屑培養基製作乃以乾重比 85 : 15 混合雜木屑與米糠後，將含水量調整至 60–65%，分裝於玻璃培養皿中，進行高溫高壓 (121℃，1.2 kg cm^{-2}) 滅菌 1 h，靜置室溫下備用。將炭角菌和香菇之供試菌株分別自保存管中取出，以 PDA 培養基進行活化，並放置於 25℃之恆溫箱中黑暗培養 7–14 d。以 5 mm 打孔器切取炭角菌和香菇之菌絲塊，分別置於距 PDA 培養基和木屑培養基 (直徑 9 cm) 直徑兩端點 2.5 cm 處，並於全黑暗 25℃環境中進行培養，每處理 5 重複。以接種後 7 d 之菌落半徑變化進行影響評估，並計算兩菌交接處和無交接處的菌落半徑比例 (菌落中心至交接處半徑/菌落中心至無交接處半徑)。本試驗進行 2 次重複。

炭角菌對腐絕藥劑之感受性試驗

《植物保護手冊》可允許使用於段木香菇之推薦用藥為 60% 腐絕可濕性粉劑，本試驗基於後續產業應用需求，選用腐絕作為供試藥劑。藥劑使用劑量將依現行公告於《植物保護手冊》中，推薦使用於段木香菇上防治綠黴病之施用量作為基準進行稀釋倍數設計，分別製備含有約 1,200、600、300、120、60、30 ppm 腐絕的 PDA 培養基進行測試，以確認可有效抑制炭角菌之藥劑濃度。以 5 mm 打孔器切取炭角菌之菌絲塊，並置於上述含有不同濃度腐絕的 PDA 培養基中，以 25℃之恆溫箱進行黑暗培養，並於培養後 7 d 記錄菌落直徑。另，將直徑 5 mm 之炭角菌菌絲塊置於 PDA 培養基中央，再將含有不同稀釋倍率的 60% 腐絕水懸劑 (稀釋 1,000×、10,000× 和 20,000×) 之濾紙圓片擺放於培養基四端點進行藥劑試驗，於生長 14 d 後，測量菌落邊緣至濾紙圓片邊緣之距離，每處理 5 重複。

數據分析方法

本次試驗所得數據，以 SAS (Statistical Analysis System) 7.1 版統計軟體進行分析，處理組間以單因子變異數分析，並以 Tukey's studentized range (honestly significant difference; HSD) 於 95% 信賴區間進行檢驗，評估處理組間有無統計學上顯著差異。

結果

炭角菌之鑑定

嘉義縣阿里山鄉達邦村菇場所採集之炭角菌子實體，在段木上以簇生或叢生發生，外觀呈棍棒狀或圓柱狀，長約 3–5 cm，直徑約 2–5 mm，表面光滑 (圖 1A)。經於實驗室組織分離後，可於 PDA 平板上進行人工培養，選取供試菌株 CYX-1 之菌落初期呈現白色，菌絲濃密生長，培養 7–14 d 後菌絲可轉為墨綠色 (圖 1B)。菌絲經光學顯微鏡觀察，可發現菌絲無色且具有隔膜 (septate) 等構造 (圖 1C)，但無分生孢子或子囊孢子之產生。為進一步鑑定該菌株，將此真菌之 ITS 序列與 NCBI 基因資料庫進行分析比對，發現供試菌株 CYX-1 和 *Xylaria scruposa*、*Xylaria polymorpha* 等炭角菌科真菌之 ITS 序列具有 89–90% 的相似度。

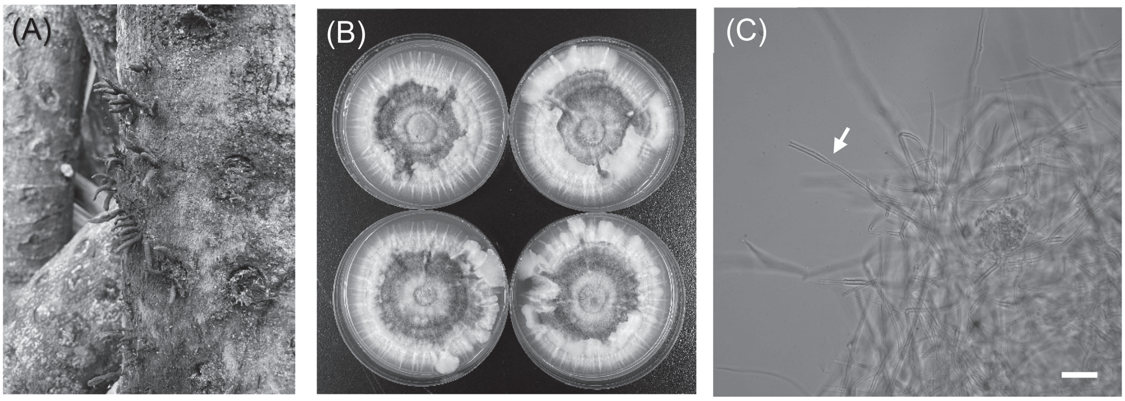


圖 1.　炭角菌之外觀。(A) 段木上炭角菌之子實體型態；(B) 培養於 PDA 培養基之菌落形態；(C) 於光學顯微鏡下之炭角菌菌絲具有隔膜 (箭頭處)。

Fig. 1.　Appearance of *Xylaria* sp. (A) Fruiting bodies on shiitake wood log; (B) colonies on potato dextrose agar (PDA) media; and (C) the regular septate hyphae (arrowed) with branches (scale bar = 10μm).

因此，依據田間子實體外觀和 ITS 序列分析結果，初步將阿里山鄉段木上所分離之菌株 CYX-1 鑑定為 *Xylaria* 屬之真菌。

炭角菌與香菇之交互關係

為瞭解炭角菌和香菇間的交互影響情形，將兩菌之供試菌株 CYX-1 與 Br-1 於 PDA 和木屑平板上進行對峙培養，結果顯示，經於 25℃下靜置培養 7 d 後，不管於 PDA (圖 2) 或木屑 (圖 3) 培養基上，兩菌之菌落邊緣即互相接觸，其中炭角菌相較香菇，菌絲更為潔白且濃密，而香菇菌絲於接觸後除生長受影響外，菌絲更出現弱化；此外，由培養基背面觀察菌絲交接處，出現些許菌絲褐化之現象。此時，香菇菌絲自菌落中心點至交接處平均長為 1.2700 ± 0.1250 cm，與正常生長之菌絲長度 3.1200 ± 0.0920 cm 具有顯著差異；而炭角菌於上述兩種培養條件下，菌絲長度雖也具有顯著差異 (分別為 2.1200 ± 0.0490 cm 及 2.5600 ± 0.0340 cm)，但影響幅度較小，如表 1。經 28 d 培養後，發現炭角菌菌絲甚至包覆香菇菌絲繼續生長，且交接處之香菇菌絲褐化情形更為明顯。

炭角菌對腐絕藥劑之感受性試驗

在測試炭角菌 CYX-1 對 60% 腐絕水懸劑的感受性試驗中，結果顯示炭角菌在含有不同濃度腐絕 PDA 培養基上之菌落生長 14 d 後，於供試最低濃度之 30 ppm 腐絕處理下菌絲完全受到抑制，而對照組菌落大小則為 8 ± 0.1cm (圖 4)。此外，為進一步釐清藥劑之擴散抑制效果，使用含有不同稀釋倍數腐絕的濾紙圓片進行試驗，並以菌落至濾紙圓片的距離作為判定抑制效果。經 21 d 培養後，結果顯示炭角菌在稀釋 1,000× 腐絕和對照組 (無菌水) 處理下抑制帶大小具有顯著差異，於稀釋 10,000× 和 20,000× 的處理間亦具有顯著差異，但此兩種稀釋倍數的處理和對照組則無顯著差異，結果如圖 5 所示。由炭角菌對藥劑感受性試驗結果可知，腐絕具有防治炭角菌之潛力。

討論

段木在長期高溫多濕的環境中，易受到如褐腐、白腐和軟腐等真菌或細菌的侵染而導致自然劣化分解 (Schwarze 2007)，進而影響段木香菇的品質或產量。依台灣嘉義縣阿里山鄉於 2021–2022 年間田間調查結果，發現段木香菇栽培時常見之有害真菌，經初步診斷後，以真菌性病原菌為主，其中大多屬於子囊菌和擔子菌門，包含多孔菌、炭團菌、裂褶菌、炭角菌、薄多孔菌及綠黴菌等，多數屬於木材腐朽菌 (Abe 1989)。

依據前人研究指出炭角菌之子實體外觀為圓柱形，高度和寬度約為 30–40 mm × 2–5 mm，成熟後，子座上之子囊殼內著生子囊，

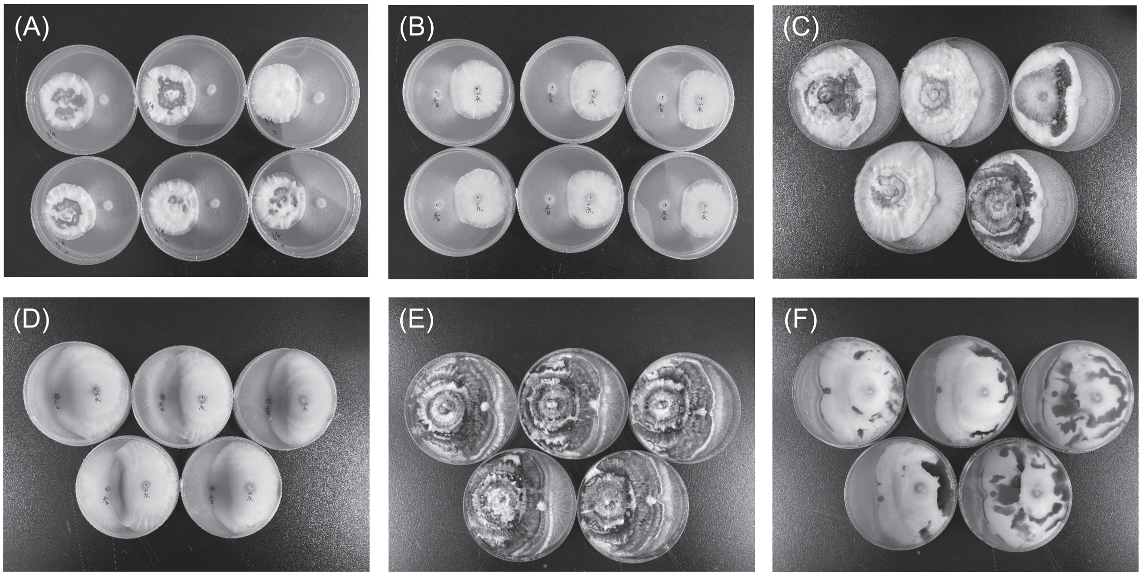


圖 2. 炭角菌和香菇於 PDA 培養基上對峙培養 (A、C、E 左和 B、D、F 右為炭角菌)。(A–B) 於培養後 7 d 兩菌落接觸；(C–D) 培養 14 d 後，炭角菌菌絲覆蓋香菇菌絲，且背面出現褐化現象；(E–F) 28 d 後，炭角菌菌落墨綠化，且背面褐化更為明顯。

Fig. 2. The dual culture assay between *Xylaria* sp. CYX-1 and *Lentinula edodes* Br-1 on potato dextrose agar (PDA) media (A, C, E left and B, D, F right was *Xylaria* sp.). (A–B) Two colonies contacted each other 7 d after inoculation; (C–D) mycelium of shiitake was covered by that of *Xylaria* sp., and the backsides of the PDA media of the former turned brown 14 d after inoculation; (E–F) surfaces of the colony of *Xylaria* sp. turned green, and browning of the backside of media became significantly 28 d after inoculation.

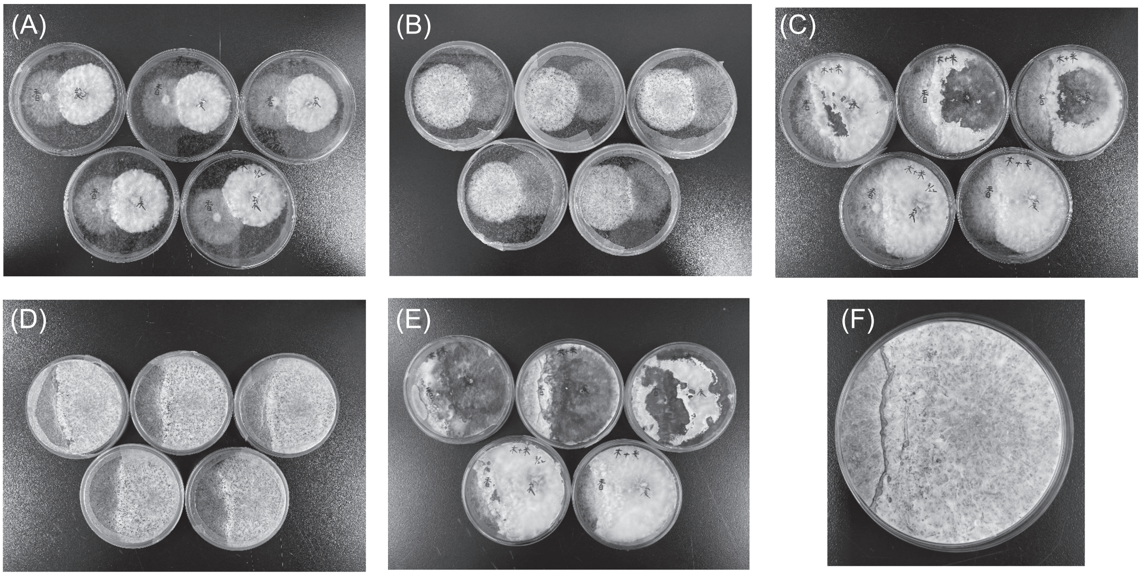


圖 3. 以 15% 米糠之木屑培養基對峙培養測試炭角菌 CYX-1 對香菇 Br-1 菌絲生長之影響。培養 (A–B) 9 d；(C–D) 16 d；(E–F) 28 d 之菌落形態。

Fig. 3. The effect of *Xylaria* sp. CYX-1 on mycelial growth of *Lentinula edodes* Br-1 by dual culture on a sawdust medium supplemented with 15% of rice bran. The colony morphology of two isolates (A–B) 9 d; (C–D) 16 d; and (E–F) 28 d after inoculation.

表 1. 炭角菌和香菇於 PDA 培養基上對峙結果 (單位：cm)。

Table 1. The dual culture of *Xylaria* sp. CYX-1 and *Lentinula edodes* Br-1 on potato dextrose agar (PDA) plates.

	Colony radius (cm)		
Isolate	A[z]	B	B/A
CYX-1	2.5600 ± 0.0340 b[y]	2.1200 ± 0.0490 a	0.8300 ± 0.0270 a
Br-1	3.1200 ± 0.0920 a	1.2700 ± 0.1250 b	0.4100 ± 0.0146 b

[z] A: The colony radius was measured 7 d after mycelial growth along in normal; B: the colony radius was measured 7 d after mycelial growth with dual culture on media.

[y] Data (means ± standard error) with different letters in each column are significantly different according to Tukey's studentized range (honestly significant difference; HSD) test at $P < 0.05$.

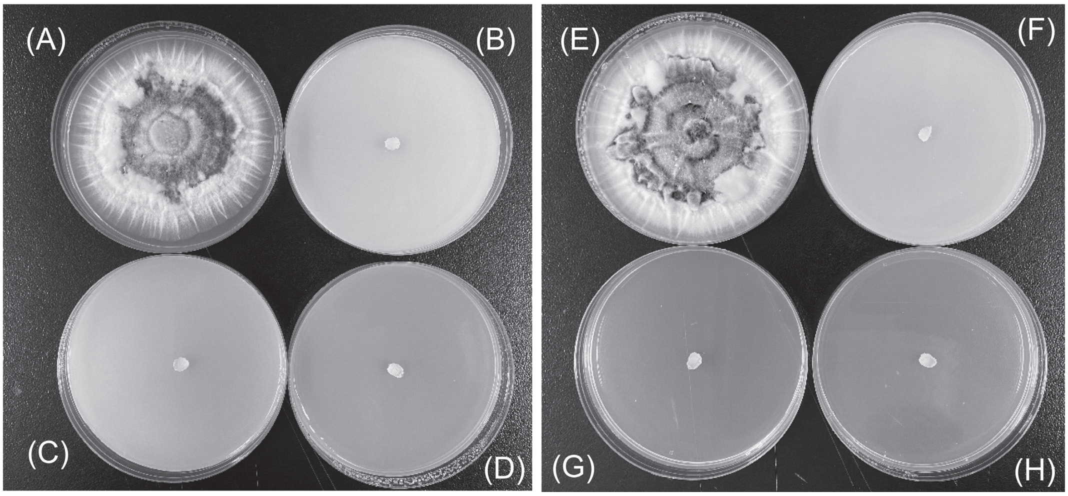
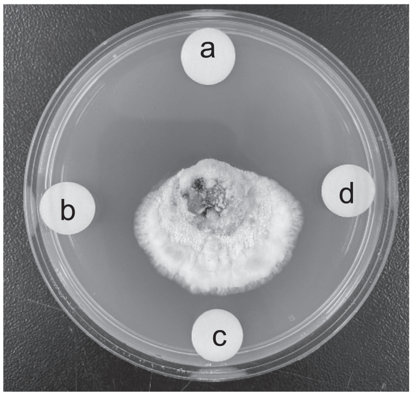


圖 4. 炭角菌在含有不同濃度腐絕的 PDA 培養基上之生長情形。

Fig. 4. The mycelial growth of *Xylaria* sp. CYX-1 grown on potato dextrose agar (PDA) media with different concentrations (A, E: 0 ppm; B: 1,200 ppm; C: 600 ppm; D: 300 ppm; F: 120 ppm; G: 60 ppm; and H: 30 ppm) of thiabendazole.



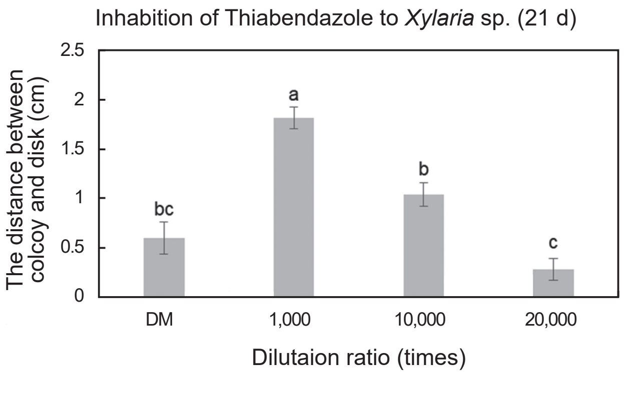


圖 5. 以濾紙圓盤法測試不同稀釋倍數腐絕 (60% SC) 對炭角菌菌絲抑制之情形。(a：稀釋 1,000×；b：稀釋 10,000×；c：稀釋 20,000×；d：無菌水)。

Fig. 5. The inhibition of thiabendazole [60% suspension concentrates (SC)] at different dilution folds on mycelial growth of *Xylaria* sp. CYX-1 with filter paper-disk method [a: 1,000 dilution fold; b: 10,000 dilution fold; and c: 20,000 dilution fold; d: distilled water (DW)]. Data (means ± standard error) with different letters are significantly different according to Tukey's studentized range (honestly significant difference; HSD) test at $P < 0.05$.

大小約 180–220 µm × 7–8 µm。每個子囊上具有 8 個子囊孢子，孢子為褐色橢圓形，18–20 µm × 6–7 µm (Raymundo *et al*. 2014; Hashemi *et al*. 2015)，和本研究自阿里山鄉所採集之供試菌株 CYX-1 於田間的子實體型態一致，而過往炭角菌之鑑定多仰賴有性構造和子囊孢子之形態特徵進行區分，但由於本試驗未能取得子囊孢子的相關資料，僅能由 ITS 序列分析結果初步將試驗菌株鑑定為 *Xylaria* sp.，後續為進一步鑑定此菌株，將擴大調查該區所產生之炭角菌子實體之巨觀與微觀性狀，包含子實體、子座、子囊殼、子囊及子囊孢子之大小，形狀及顏色等；同時亦將已分離之菌株接種於段木或木屑太空包中，並誘導其子實體產生，以蒐集其子囊孢子進行鑑定，並規劃利用多基因解序之方法，進行更進一步之親源分析。

在木材腐朽菌之生長過程中，所需的主要養分可分成碳素源與氮素源兩類，其中段木中之纖維素與木質素即是作為碳素源的主要來源。真菌可透過所產生孢子萌發生成菌絲所分泌的酵素，包括纖維二糖水解酶 (cellobiohydrolase)、內切型葡萄糖分解酶 (endoglucanase) 及外切型葡萄糖分解酶 (exoglucohydrolase) 等，降解植物細胞壁中的木質素和纖維素 (Baldrian & Valášková 2008)，亦會透過鐵離子以芬頓反應生成氫氧自由基 (hydrothyl radial)、超氧自由基 (peroxyl radical) 及過氧化氫自由基 (hydroperoxyl radical) 等活性氧，降解木質細胞組成 (Kumar *et al*. 2021)。而香菇也是利用段木中之木質素等進行生長，因此在有機物資源有限的情況下，木材腐朽菌勢必會和香菇競爭段木中的營養與生長空間，導致香菇菌絲生長受阻，甚至影響後續的出菇量。在競爭相同生態位 (niche) 之情況下，菌勢較強的一方可能因其孢子具有快速的傳播和發芽能力、菌絲生長較為快速及良好的物質分解能力等優勢使其可快速擴展，並造成菌勢較弱的一方菌絲弱化，甚至出現死亡現象。Boddy (2000) 研究指出真菌間的競爭關係，可依生態位事先是否已被其他真菌占據區分為初級資源掠奪 (primary resource capture) 和次級資源掠奪 (secondary resource capture)，而影響的機制則包括分泌抗生物質、菌絲的干擾及超寄生。其中大量的菌絲相互接觸 (gross mycelium contact)，使接觸面之菌絲產生形態變化亦為木材腐朽菌常見的交互影響結果 (Boddy 2000)。

炭角菌於自然界中以腐生為主，兼具寄生的能力，屬於兼性寄生，主要生長在腐朽的木頭、落葉或土壤等有機質中。在 Wang & Cui (2010) 和 Du & Cao (2007) 等人的研究中指出總狀炭角菌 (*Xylaria pedunculata*) 之菌絲與平菇 (*Pleurotus ostreatus*)、香菇、毛木耳 (*Auricularia polytricha*)、杏鮑菇 (*Pleurotus eryngii*) 及白靈菇 (*Pleurotus nebrodensis*) 等菇類菌絲接觸後，後者之菌絲初期皆能與總狀炭角菌形成明顯的拮抗線，但經進一步的培養後，菇類菌絲甚至可覆蓋炭角菌之菌絲繼續向前生長，具有較強的拮抗和抑制能力。惟有雞腿菇 (*Coprinus comatus*) 對其無競爭優勢，起初於交界處出現模糊的淺褐色拮抗線，但隨時間的推展，雞腿菇之菌絲將會逐漸被炭角菌包圍，甚至可於雞腿菇原本的生長點形成炭角菌子座。進一步透過光學顯微鏡可發現交界處菌絲出現扭曲、侵入和纏繞等現象，因此推測炭角菌屬真菌對部分食用菌仍具有病原性 (Du & Cao 2007; Wang & Cui 2010)。本試驗分離得到的炭角菌 CYX-1 在與香菇 Br-1 對峙培養的結果，和 Boddy (2000) 研究指出的菌絲相互接觸 (gross mycelium contact) 現象及上述以總狀炭角菌與雞腿菇菌絲接觸後所產生的反應一致，於接觸面會形成明顯的阻隔帶，並隨著培養時間的拉長，炭角菌將持續朝香菇菌落生長，尤其在木屑培養基上更可觀察到明顯的炭角菌逐漸覆蓋香菇菌絲之過程，亦可發現香菇菌絲出現弱化情形。因此，由本研究之木屑和 PDA 培養基的對峙實驗結果可知，在具有豐富的碳素源和氮素源的營養條件下，炭角菌 CYX-1 之生長勢和香菇具有顯著差異，甚至可覆蓋香菇菌絲繼續生長，初步推測所分離之炭角菌於環境適宜時，不僅具有與香菇競爭段木上生長空間與營養之能力，更可能對香菇產量造成危害，成為香菇之競爭菌。此外，於 PDA 培養基背面交接處，香菇菌絲顏色會從原先的淺白色轉為深褐色，推測可能和細胞內和細胞間色素的產生，或香菇菌絲受到影響，

如：酚類氧化活性改變等，並分泌防禦之二次代謝物有關 (Boddy 2000)。由於香菇屬於擔子菌門真菌，可生成扣子體構造，但炭角菌無此特性，因此未來可利用此差異，再使用光學顯微鏡或掃描式電子顯微鏡觀察炭角菌和香菇之菌絲互相纏繞和兩者菌絲是否出現型態上的變化，以驗證炭角菌對香菇之病原性。

炭角菌之子實體成熟後，子座上之子囊殼內可產生大量子囊孢子，而子囊孢子會隨風、雨或空氣進行傳播，於環境適宜時侵染周邊健康段木 (Thomas *et al*. 2016)。為降低炭角菌對段木香菇造成擴大影響，優先選用在《植物保護手冊》中可使用於段木香菇栽培的推薦用藥 - 腐絕測定炭角菌對本藥劑之感受性，試驗結果顯示本菌對腐絕的感受性高，在極低濃度下即可有效抑制炭角菌的生長。據此，菇農如栽種前於環境中施用少量的腐絕，且配合上適當的田間衛生管理，除可有效抑制炭角菌外，還可同時抑制其他環境中之子囊菌或不完全菌的病原菌，如：綠黴菌、紅色麵包黴及木黴菌等。此外，炭角菌對香菇產量之影響取決於其在生產過程中的侵入時機，因此後續也將針對炭角菌侵入段木後的繁殖至子實體之產生過程進行深入調查與研究，盼能提供最佳的藥劑施用時間與藥效做為防治參考，使段木香菇之產量與品質有所提升。

近年來，炭角菌的研究多著重於分類與鑑定等方面，對於其二次代謝物之生物活性亦有所研究 (Liu *et al*. 2007)。此外，目前已發現炭角菌可產生真菌上常見的氣態和非氣態的物質，前者包含 sequiterpenoids、esters 和 alcohols，而後者則有 terpenoids、cytochalasins、mellein、alkaloids、polyketides 和 aromatic compounds，而其他二次代謝物也被發現具有和農業與醫藥相關的生物用途。醫療上可分成抗生、細胞毒性和抗氧化等部分，其中炭角菌所分泌的抗生物質，如 xylabisboein A 和 B、methylmellein 及 ergosterol peroxide 等，對於人體病原菌 *Staphylococcus aureus*、*Trichophyton rubrum*、*Hormodendrum compactum* 及 *Candida albicans* 等皆具有抑制的效果。而在農業上則可應用於開發病蟲害防治，目前已知炭角菌之代謝物對於秋行軍蟲 (*Spodoptera frugiperda*)、小菜蛾 (*Plutella xylostella*) 等害蟲及稻熱病菌 (*Pyricularia oryzae*)、小麥赤霉病菌 (*Gibberella saubinetti*)、猝倒病菌 (*Pythium ultimum*) 等作物病原菌具有抑制的效果 (Jang *et al*. 2007; Macías-Rubalcava & Sánchez-Fernández 2017)，因此本研究於未來也可進一步探討國內炭角菌用於醫療和作物病蟲害防治上之潛力。

目前在段木香菇之有害生物方面研究甚少，本研究為第一篇探討炭角菌發生於台灣段木香菇的報導，後續將持續調查台灣其他產區的炭角菌於段木香菇上發生之情形，並進行段木接種試驗以釐清炭角菌和香菇在自然環境中實際的交互影響。另也將進一步的探討在對峙培養時香菇菌絲出現褐化反應時的防禦基因表現，此外，本研究亦發現利用腐絕可有效抑制炭角菌之菌絲生長，盼於未來能作為段木香菇炭角菌防治策略擬定之參考依據。

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Identification and Fungicide Sensitivity of *Xylaria* sp. Grown on Shiitake Wood Log in Taiwan

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Abstract

Yu, S. S. and Y. S. Lu. 2022. Identification and fungicide sensitivity of *Xylaria* sp. grown on shiitake wood log in Taiwan. J. Taiwan Agric. Res. 71(4):331–341.

In recent years, the average production of wood log shiitake in Taiwan was 264 tons, accounting for 0.6% of the market share in shiitake. The planting areas are mainly distributed in indigenous community of Yilan, Taoyuan, Hsinchu, Miaoli, Nantou, and Pingtung. Common microorganisms occurring during wood log cultivation belong to wood-decaying fungi. In addition, there was little domestic research about the effect of wood-decaying fungi on the yield and quality of wood log shiitake. Due to the "under-forest economy" policy promoted by the Council of Agriculture, Executive Yuan, ROC, the planting area of wood log shiitake has increased yearly. The government has also paid the attention to the diseases and pests or competitors that occurred during the cultivation of wood log shiitake. In this study, a fungus was isolated from the shiitake wood log collected from Alishan, Chiayi, and evaluated in our Mushroom Research Laboratory. After comparing the appearance of the fruiting bodies in the field and analysis of its ITS sequence, the fungus was preliminarily identified as *Xylaria* sp. A dual culture assay showed when the mycelium of *Xylaria* sp. CYX-1 confronted with that of *Lentinula edodes* Br-1 on a potato dextrose agar (PDA) medium, the mycelial growth of the latter was significantly inhibited. After two weeks of culturing on the medium, the mycelium of *Xylaria* sp. could cover that of *L. edodes*. It showed that *Xylaria* sp. CYX-1 was detrimental to the mycelial growth of *L. edodes* Br-1 and could be the competitor of the latter. The recommended fungicide thiabendazole for application in the cultivation of shiitake was used in this study to test the fungicide sensitivity of *Xylaria* sp. CYX-1. The result showed that the mycelium of *Xylaria* sp. CYX-1 was totally inhibited on the PDA medium with 30 ppm of thiabendazole and in a filter paper-disk test with 1,000 dilution fold of thiabendazole [60% suspension concentrates (SC)]. Therefore, thiabendazole could potentially be used to control *Xylaria* sp. This is the first report on the possibility of *Xylaria* sp. as a competitor of shiitake cultivation on the wood log in Taiwan. Further surveys of the damage caused by *Xylaria* sp. in other planting areas of wood log shiitake will be needed. The results of the fungicide sensitivity of *Xylaria* sp. to thiabendazole may provide an important reference to control *Xylaria* sp. during shiitake wood log cultivation.

Key words: *Xylaria* sp., Wood log shiitake, Under-forest economy, Thiabendazole.

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研究報告

運用氣象資料預測當期荔枝產量之可行性研究

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摘要

方信秀、邱國棟、徐智政、李文立。2022。運用氣象資料預測當期荔枝產量之可行性研究。台灣農業研究 71(4):343–357。

荔枝產量每年受到冬季氣溫影響甚劇，低溫可刺激花芽穩定分化，但遇到暖冬年則因花芽分化不穩定與開花比例下降導致減產。本研究調閱主產區鄰近氣象站過去 9 年 11 月至隔年 2 月的氣象資料，將每日處於 10–35℃的小時數加總後，依荔枝品種不同分別與當期批發市場荔枝交易總量進行回歸分析。結果顯示 12 月的氣溫與當期的產量相關性最高，並以『較長的低溫期』比『較寒冷的溫度』對產量的影響更關鍵，「玉荷包」、「黑葉」與「糯米糍」荔枝分別在每日低於 24℃、13℃與 22℃的小時數加總與當期產量進行回歸分析的決定係數 (R^2) 可達 0.6938、0.8578 與 0.8215。本研究結果顯示，未來可依荔枝品種不同，將產區 12 月低於特定溫度的小時數加總後帶入回歸方程式計算，即可提早預估當年度的荔枝產量。此創新方法可作為農政單位產銷調節，或荔枝產銷業者提早規劃內外銷訂單之參考資料。

關鍵詞：荔枝、產量、暖化、氣象資料。

前言

荔枝 Litchi (*Litchi chinensis* Sonn.) 為無患子科常綠果樹，花芽分化受到溫度、水分逆境及枝條成熟度所影響 (O'Hare 2002; Malhotra *et al*. 2018; Su *et al*. 2021)。溫度可決定新芽發展為葉片或是花朵 (Menzel *et al*. 1989)，惟必需有一段足夠的低溫期才可誘導花芽分化 (Chen & Huang 2005; Chen *et al*. 2013)。冬季低溫誘導荔枝花芽分化成花芽混合葉芽基體 (rudimentary leaves) 及花芽基體 (panicle primordia)，若持續處於足夠低的溫度，葉芽基體則停止生長，花芽基體則持續發展為完整的圓錐花序。暖冬或暖春可使葉芽基體持續生長為完整葉片，而花芽基體則停止生長或萎縮，也可能形成帶葉花序，影響開花率 (Zhou *et al*. 2008, 2012; Yang *et al*. 2017)。由於全球暖化，暖冬或是溫暖的春天會抑制花芽分化或花芽敗育而影響荔枝產量 (Kumar 2014; Liu *et al*. 2019)。

依據 2020 年農糧署農業統計年報顯示，台灣荔枝的栽培面積為 9,727 ha (https://agr.afa.gov.tw/afa/afa_frame.jsp)。另依農產品批發市場交易行情站資料顯示，台灣批發市場交易主要荔枝品種為「黑葉」、「玉荷包」、「竹葉黑」、「糯米糍」及「桂味」。因不同荔枝品種對誘導花芽分化的低溫需求不同，在台灣長期栽培下不同荔枝品種逐漸形成各自主產地。「黑葉」荔枝集中於台中、南投與彰化，「玉荷包」荔枝集中於高雄與屏東，「竹葉黑」荔枝產地分散於嘉義、台南、台中。「糯米糍」荔枝主要集中為南投、台中。「桂味」荔枝則分布於台中、南投、新竹 (Zhang & Teng 2011)。

由於冬季氣溫偏高影響荔枝開花著果穩定性，若冬季有足夠低溫期，則開花率普遍較穩定。有學者利用氣象資料進行荔枝產量推估，營養生長期及開花期的降雨對產量有負面影響，抽花穗期每日最低溫和開花期每日最高溫

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之溫度較高時產量較高，不同的荔枝品種對氣溫變化的敏感度不同。中國大陸東莞荔枝種植面積約 1.4 萬公頃，以「糯米糍」、「桂味」及「懷枝」為主要栽培品種，使用結果大小年對比當年度氣象資料，結果顯示以 1 月上旬的平均氣溫與當年荔枝產量密切，相關係數 r = -0.5443，表示平均氣溫及產量呈現負相關 (Wang 2001; Qi & OuYang 2017, 2019)。

因低溫具有誘導荔枝芽點休眠與刺激花芽分化的功能，但目前對於『低溫期較久』與『較冷的低溫』哪個對荔枝產量較關鍵尚不明瞭。本研究調閱氣象資料，使用每個月低於高溫臨界溫度的『度數』加總，以此數值呈現當月份『是否夠寒冷』。舉例來說：將高溫臨界溫度為 35℃計算時，若某小時溫度為 30℃，則低於 35℃以下的度數為 5℃；或是某小時溫度為 10℃，低於 35℃以下的度數則為 25℃，當把整個月份每小時低於 35℃以下的度數加總數值愈大，代表當月份愈寒冷。所以『高溫臨界溫度以下的度數』加總數值愈大，若批發市場荔枝『銷售量』也愈多時，兩者即呈現正相關。又本研究中使用每個月低於高溫臨界溫度的『小時數』加總，為呈現當月份『低溫期是否夠久』。舉例來說：臨界溫度為 20℃計算時，當天 24 h 中有 5 h 低於 20℃時，則取得數值為 5；當天 24 h 中有 18 h 低於 20℃時，則取得數值為 18。若把整個月份低於 20℃的小時數加總數值愈大，代表當月份低溫期較久。所以『高溫臨界溫度以下的小時數』加總數值愈大，若批發市場荔枝『銷售量』也愈多時，兩者即呈現正相關。

本研究利用不同荔枝品種主產區 2013–2022 年的氣象站資料，各別使用 10–35℃之間的氣溫作為為高溫臨界溫度，加總每個月份的高溫臨界溫度以下『度數』與『小時數』加總，與全台批發市場的荔枝交易總量，進行回歸分析。推估影響荔枝產量最相關月份的氣象資料，並觀察不同高溫臨界溫度條件的決定系數 (R^2)，以最高的決定系數條件，運用回歸方程式於產期前提早推估該期荔枝產量，以推估『低溫期較久』與『較冷的低溫』那個對荔枝產量較關鍵，分析結果另可作為農政單位或荔枝產業提早進行農業政策研擬或內外銷規劃之重要參考資料。

材料與方法

氣象資料取得

本研究選定 5 個台灣主要荔枝栽培品種之主產地鄰近氣象站為資料來源，全數氣象資料由中央氣象局觀測資料查詢網站 (http://e-service.cwb.gov.tw/HistoryDataQuery/index.jsp) 下載。「玉荷包」荔枝資料來源為高雄溪埔站 (C0V350，經度 120.4467E、緯度 22.7385N)，「黑葉」荔枝資料來源為台中中竹林站 (C0F9A0，經度 120.751061E、緯度 24.103556N)，「竹葉黑」荔枝資料來源為嘉義站 (467480，經度 120.432906E、緯度 23.495925N)，「糯米糍」資料來源為南投草屯站 (C0H960，經度 120.680850E、緯度 23.973672N)，「桂味」資料來源為新竹寶山站 (C0D580，經度 121.025192E、緯度 24.735006N)。因部分氣象站為 2013 年新架設，所以統一取用 2013–2022 年 11、12、1 和 2 月等 4 個月份的每日氣象資料，每日的氣象資料以 1 h 為 1 個資料點，每日有 24 筆資料。每個氣象站共取得 25,920 h 的資料進行分析。高雄站 (467441，經度 120.312389E、緯度 22.730500N) 與台中站 (467490，經度 120.6840E、緯度 24.1457N) 1995–2021 年氣象資料亦由上述網站取得。

荔枝批發市場交易量資料取得

荔枝銷售管道包括網路直銷、大賣場、超商、團購、外銷、行口、批發市場及產地直銷等多元銷售方式，要精準估算當年荔枝產量實屬不易。本研究直接取用『批發市場的交易總量』作為回歸分析基礎資料，主要是因批發市場清楚記錄每筆荔枝交易資料，涵括全台數千個荔枝農戶銷售資料。因樣本數量多，有豐產年銷售量較多、減產年銷售量較少之特性，且批發市場包括台北市、台北二、台北一、板橋區、三重區、宜蘭市、桃農、台中市、豐原區、東勢區、南投市、嘉義市、高雄市、鳳山區及台東市等 15 個市場，平均分布全台，對於荔枝產量具有相當的代表性。

不同荔枝品種當年的產量，以批發市場的總交易量作為參考資料。於農產品批發市場交易行情站網站 (https://amis.afa.gov.tw/main/Main.aspx)，分別取得2014–2022年的「玉荷包」、「黑葉」、「竹葉黑」、「糯米糍」及「桂味」荔枝每年於所有批發市場的交易總量。因網站資料無法顯示到貨荔枝產區，本研究直接依各品種批發市場交易總量進行回歸分析。

資料整理及回歸分析

所有資料整理、製表及回歸分析使用 Microsoft Excel 2016 進行。先撰寫巨集資料，執行巨集將氣象資料各別自動匯入，並同時自動分析資料。本研究將臨界溫度範圍設為 10–35℃，並特別將高溫臨界溫度設於 35℃的高溫標準，目的為涵蓋大部分的溫度資訊，設於 35℃時可同時瞭解高溫期與低溫期的資訊；如果臨界溫度最高只設於 25℃以下的溫度，只可得知是否有足夠的低溫期，但卻無法瞭解是否有過多的高溫期促進營養生長或抑制花芽分化。

巨集資料匯入每日氣象資料，即可自動計算『每個月低於高溫臨界溫度的小時數總合』以及『每個月低於高溫臨界溫度的度數總合』，最後再將取得的數值分別和『當季批發市場總交易量』進行回歸分析。

因過去不瞭解溫度影響荔枝產量最關鍵的月份與臨界溫度，觀察 5 個不同荔枝品種的回歸分析結果，先找出決定係數 (R^2) 平均值最高的月份，再找出決定係數最高之臨界溫度，即以此臨界溫度的回歸方程式作為預估未來產量使用。

結果

『低於高溫臨界溫度以下的小時數加總』氣象資料與批發市場荔枝總交易量相關性分析結果

綜合比較「玉荷包」、「黑葉」、「竹葉黑」、「糯米糍」及「桂味」等 5 種荔枝品種『11 月、12 月、1 月、2 月、12–1 月與 11–2 月低於臨界溫度以下的小時數加總』與『當期批發市場荔枝總量』之相關性分析 (圖 1、2、3、4、5)。結果顯示，不同月份決定係數的平均值，以 12 月之決定係數最高。

進一步觀察 12 月份資料，「玉荷包」荔枝批發市場總交易量與臨界溫度 24℃以下小時數總合之決定係數 (R^2) 0.6938 最高 (圖 1A)。「黑葉」荔枝批發市場總交易量與臨界溫度 13℃以下小時數總合之決定係數 (R^2) 0.8578 最高 (圖 2A)；「竹葉黑」荔枝批發市場總交易量與臨界溫度 20℃以下小時數總合之決定係數 (R^2) 0.5224 最高 (圖 3A)；「糯米糍」荔枝批發市場總交易量與臨界溫度 22℃以下小時數總合之決定係數 (R^2) 0.8215 最高 (圖 4A)；「桂味」荔枝批發市場總交易量與臨界溫度 28℃以下小時數總合之決定係數 (R^2) 0.2915 最高 (圖 5A)。

『低於臨界溫度以下的度數總合』氣象資料與批發市場荔枝總交易量相關性分析結果

綜合比較「玉荷包」、「黑葉」、「竹葉黑」、「糯米糍」及「桂味」等 5 種荔枝品種『11 月、12 月、1 月、2 月、12–1 月與 11–2 月低於臨界溫度以下的度數總合』與『當期批發市場荔枝總量』之相關性分析 (圖 1、2、3、4、5)。結果顯示不同月份決定係數的平均值，也以 12 月之決定係數最高。

進一步觀察 12 月份資料，「玉荷包」荔枝批發市場總交易量與臨界溫度 30℃以下的度數總合之決定係數 (R^2) 0.3537 最高 (圖 1B)。「黑葉」荔枝批發市場總交易量與臨界溫度 15℃以下度數加總之決定係數 (R^2) 0.8638 最高 (圖 2B)；「竹葉黑」荔枝批發市場總交易量與臨界溫度 35℃以下度數加總之決定係數 (R^2) 0.4468 最高 (圖 3B)；「糯米糍」荔枝批發市場總交易量與臨界溫度 28℃以下度數加總之決定係數 (R^2) 0.8268 最高 (圖 4B)；「桂味」荔枝批發市場總交易量與臨界溫度 35℃以下度數加總之決定係數 (R^2) 0.0798 最高 (圖 5B)。

以各品種 12 月最高決定係數之回歸方程式推估當期荔枝品種產量

據各品種 12 月最高決定係數的臨界溫度條件下，導出回歸方程式，以作為未來產量預估使用 (表 1、2 及圖 6)。結果顯示，5 個荔枝

(A)

Critical temperature	Coefficients of determination (R^2) Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
35℃	0.0183	0.1091	0.1272	0.0004	0.1202	0.0530
34℃	0.0123	0.1091	0.1272	0.0004	0.1202	0.0489
33℃	0.0046	0.1091	0.1272	0.0004	0.1202	0.0422
32℃	0.0193	0.0737	0.1272	0.0006	0.1061	0.0117
31℃	0.1238	0.0103	0.1272	0.0212	0.0354	0.0262
30℃	0.3863	0.1504	0.0531	0.1249	0.0127	0.2605
29℃	0.3899	0.2247	0.0010	0.1190	0.1069	0.2925
28℃	0.2820	0.3330	0.0674	0.1296	0.2250	0.2862
27℃	0.2306	0.4711	0.1079	0.1245	0.3414	0.3015
26℃	0.0042	0.6152	0.1694	0.1268	0.4687	0.3220
25℃	0.0789	0.6258	0.2322	0.0844	0.5092	0.2773
24℃	0.0904	0.6938	0.1698	0.0299	0.5277	0.2047
23℃	0.0280	0.6248	0.1305	0.0005	0.4674	0.1145
22℃	0.0006	0.5171	0.0125	0.0071	0.3250	0.0585
21℃	0.0091	0.3492	0.0003	0.0152	0.2071	0.0446
20℃	0.0158	0.2842	0.0076	0.0157	0.1395	0.0302
19℃	0.0112	0.2599	0.0000	0.0179	0.1391	0.0293
18℃	0.0014	0.1847	0.0232	0.0129	0.1599	0.0407
17℃	0.0005	0.1882	0.0597	0.0035	0.2023	0.0703
16℃	0.0191	0.1082	0.0255	0.0258	0.1016	0.0772
15℃	0.1078	0.0919	0.0057	0.0816	0.0461	0.0729
14℃	0.0000	0.1040	0.0002	0.1363	0.0212	0.0697
13℃	0.0000	0.0700	0.0071	0.1681	0.0257	0.0809
12℃	0.0000	0.0264	0.0250	0.0534	0.0340	0.0508
11℃	0.0000	0.2316	0.0114	0.0206	0.0275	0.0290
10℃	0.0000	0.2630	0.0065	0.0008	0.0013	0.0012
Average	0.0705	0.2626	0.0674	0.0508	0.1766	0.1114

(B)

Critical temperature	Coefficients of determination (R^2) Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
35℃	0.0074	0.3467	0.0224	0.0082	0.2394	0.1114
34℃	0.0078	0.3486	0.0234	0.0082	0.2415	0.1131
33℃	0.0082	0.3505	0.0243	0.0082	0.2436	0.1147
32℃	0.0083	0.3523	0.0253	0.0082	0.2457	0.1161
31℃	0.0075	0.3536	0.0263	0.0082	0.2472	0.1165
30℃	0.0043	0.3537	0.0272	0.0078	0.2482	0.1139
29℃	0.0004	0.3532	0.0277	0.0067	0.2487	0.1073
28℃	0.0012	0.3516	0.0272	0.0052	0.2476	0.0980
27℃	0.0065	0.3446	0.0249	0.0033	0.2405	0.0859
26℃	0.0086	0.3288	0.0212	0.0016	0.2255	0.0743
25℃	0.0046	0.3034	0.0150	0.0004	0.1997	0.0632
24℃	0.0006	0.2694	0.0087	0.0000	0.1654	0.0523
23℃	0.0005	0.2349	0.0045	0.0000	0.1337	0.0450
22℃	0.0041	0.2050	0.0027	0.0000	0.1102	0.0415
21℃	0.0056	0.1819	0.0028	0.0001	0.0966	0.0400
20℃	0.0040	0.1647	0.0042	0.0011	0.0890	0.0425
19℃	0.0002	0.1469	0.0062	0.0049	0.0811	0.0467
18℃	0.0030	0.1238	0.0064	0.0154	0.0643	0.0487
17℃	0.0165	0.1080	0.0039	0.0374	0.0430	0.0485
16℃	0.0320	0.0832	0.0011	0.0627	0.0208	0.0413
15℃	0.1364	0.0869	0.0002	0.0719	0.0120	0.0343
14℃	0.0000	0.0897	0.0000	0.0518	0.0061	0.0209
13℃	0.0000	0.0999	0.0000	0.0160	0.0031	0.0074
12℃	0.0000	0.1472	0.0035	0.0002	0.0003	0.0000
11℃	0.0000	0.2593	0.0230	0.0097	0.0160	0.0140
10℃	0.0000	0.2630	0.0541	0.0475	0.0527	0.0523
Average	0.0103	0.2404	0.0149	0.0148	0.1355	0.0634

圖 1.　高雄溪埔站 2013–2022 年氣象資料與當年度「玉荷包」荔枝批發市場交易量之相關性分析。(A)『不同月份低於臨界溫度以下的小時數加總』與『當期批發市場「玉荷包」荔枝總量』之決定係數 (R^2)；(B)『不同月份低於臨界溫度以下的度數加總』與『當期批發市場「玉荷包」荔枝總量』之決定係數 (R^2)。相關係數大小以紅色深淺背景表示。

Fig. 1.　Correlation analysis of meteorological data collected at Kaohsiung Xipu and the auction market sold litchi amount of 'Yu-Her-Bao' litchi during 2013–2022. (A) The coefficients of determination (R^2) of accumulated daily hours below the threshold low temperature in different months and auction market sold litchi amount in the current year; (B) The coefficients of determinations (R^2) of accumulated temperature degrees below the threshold low temperature in different months and auction market sold litchi amount in the current year. The numerical value of the coefficients of determination is represented by the shade of red background.

品種於 12 月份最高決定係數的臨界溫度不同，於決定係數最高的臨界溫度條件下，臨界溫度以下的度數與小時數加總和批發市場的銷售量皆呈現正相關的趨勢，表示荔枝於 12 月愈低溫或低溫期愈長，當期的荔枝銷售量就愈多。

討論

荔枝需經過適當的低溫期，才可以刺激花芽分化，不同荔枝品種對低溫的需求程度不一。Zhang *et al*. (1997) 將「糯米糍」以 15℃/13℃下處理 15 wk，枝梢開花率為 85.4%，20℃/15℃下為 5.9%，25℃/20℃下無開花。或將 7 種荔枝品種於白天、夜晚溫度設定為 30℃/25℃、25℃/20℃、20℃/15℃及 15℃/10℃等 4 種溫度，結果在 30℃/25℃、25℃/20℃處理完全沒有開花，15℃/10℃則全數可誘導花芽分化，其中有 5 個品種有帶葉花序，而 20℃/15℃處理條件下，7 個品種皆有不同比例的不開花、帶葉花序與全開花結果 (Menzel & Simpson 1988)。

本研究分別進行『低於高溫臨界溫度以下

(A)

Critical temperature	Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
	Coefficients of determination (R^2)					
35℃	0.0723	0.0192	0.0334	0.0691	0.0277	0.0520
34℃	0.0723	0.0192	0.0334	0.0691	0.0277	0.0520
33℃	0.0723	0.0192	0.0334	0.0691	0.0277	0.0520
32℃	0.0723	0.0192	0.0334	0.0691	0.0277	0.0520
31℃	0.0723	0.0192	0.0334	0.0691	0.0277	0.0520
30℃	0.0498	0.0192	0.0334	0.0521	0.0277	0.0425
29℃	0.0000	0.0146	0.0334	0.0314	0.0250	0.0159
28℃	0.1502	0.0033	0.0334	0.0023	0.0163	0.0064
27℃	0.4538	0.0056	0.0130	0.0093	0.0005	0.1378
26℃	0.4751	0.0833	0.0064	0.0486	0.0188	0.2999
25℃	0.4456	0.2005	0.0079	0.0540	0.1157	0.3577
24℃	0.4656	0.3825	0.0743	0.0315	0.2668	0.3666
23℃	0.3992	0.5475	0.1660	0.0439	0.4049	0.4389
22℃	0.3691	0.5487	0.1983	0.0536	0.4176	0.4759
21℃	0.3551	0.5633	0.2300	0.0528	0.4469	0.5147
20℃	0.4813	0.6220	0.3046	0.0676	0.5190	0.5486
19℃	0.4728	0.6273	0.2457	0.0598	0.5126	0.4830
18℃	0.2756	0.6426	0.2990	0.0212	0.5693	0.4172
17℃	0.2147	0.6706	0.2524	0.0139	0.5634	0.3881
16℃	0.2257	0.7398	0.2613	0.0206	0.6329	0.4632
15℃	0.2234	0.8244	0.2860	0.0558	0.7317	0.5638
14℃	0.3733	0.8349	0.3694	0.1699	0.7833	0.6517
13℃	0.3832	0.8578	0.3181	0.2629	0.7096	0.6410
12℃	0.4149	0.8478	0.2343	0.2758	0.5781	0.5793
11℃	0.3695	0.7364	0.0535	0.3531	0.3785	0.5048
10℃	0.5296	0.3998	0.0018	0.4510	0.0674	0.3246
Average	0.2880	0.3949	0.1380	0.0953	0.3048	0.3262

(B)

Critical temperature	Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
	Coefficients of determination (R^2)					
35℃	0.4186	0.7322	0.2029	0.1075	0.5487	0.5023
34℃	0.4288	0.7336	0.2049	0.1087	0.5511	0.5070
33℃	0.4390	0.7350	0.2068	0.1099	0.5535	0.5116
32℃	0.4492	0.7364	0.2087	0.1111	0.5558	0.5161
31℃	0.4593	0.7376	0.2106	0.1123	0.5580	0.5206
30℃	0.4695	0.7388	0.2124	0.1136	0.5601	0.5250
29℃	0.4786	0.7400	0.2143	0.1148	0.5622	0.5288
28℃	0.4846	0.7411	0.2161	0.1157	0.5643	0.5313
27℃	0.4853	0.7424	0.2177	0.1161	0.5663	0.5321
26℃	0.4793	0.7442	0.2187	0.1163	0.5685	0.5318
25℃	0.4735	0.7474	0.2198	0.1167	0.5718	0.5318
24℃	0.4726	0.7515	0.2205	0.1172	0.5757	0.5334
23℃	0.4792	0.7554	0.2205	0.1199	0.5791	0.5359
22℃	0.4733	0.7607	0.2203	0.1224	0.5841	0.5334
21℃	0.4610	0.7667	0.2171	0.1270	0.5885	0.5287
20℃	0.4137	0.7756	0.2100	0.1309	0.5935	0.5211
19℃	0.3428	0.7861	0.1974	0.1363	0.5961	0.5141
18℃	0.2973	0.8059	0.1845	0.1476	0.5988	0.5167
17℃	0.2972	0.8252	0.1669	0.1753	0.5911	0.5294
16℃	0.3169	0.8541	0.1447	0.2155	0.5793	0.5467
15℃	0.3641	0.8638	0.1134	0.2656	0.5255	0.5353
14℃	0.4074	0.8487	0.0697	0.3087	0.4078	0.4825
13℃	0.4195	0.7937	0.0237	0.3196	0.2481	0.3926
12℃	0.4323	0.6588	0.0003	0.3258	0.0992	0.2824
11℃	0.4940	0.4883	0.0155	0.3241	0.0088	0.1584
10℃	0.5296	0.3750	0.0439	0.2749	0.0044	0.0676
Average	0.4333	0.7399	0.1685	0.1674	0.4900	0.4776

圖 2. 台中中竹林站 2013–2022 年氣象資料與當年度「黑葉」荔枝批發市場交易量之相關性分析。(A)『不同月份低於臨界溫度以下的小時數加總』與『當期批發市場「黑葉」荔枝總量』之決定係數 (R^2)；(B)『不同月份低於臨界溫度以下的度數加總』與『當期批發市場「黑葉」荔枝總量』之決定係數 (R^2)。相關係數大小以紅色深淺背景表示。

Fig. 2. Correlation analysis of meteorological data at Taichung Zhongzhulin and the auction market sold litchi amount of 'Hei-Yeh' litchi during 2013–2022. (A) The coefficient of determinations (R^2) of accumulated daily hours below the threshold low temperature in different months and auction market sold litchi amount in the current year; (B) The coefficient of determination (R^2) of accumulated temperature degrees below the threshold low temperature in different months and auction market sold litchi amount in the current year. The numerical value of the coefficients of determination is represented by the shade of red background.

的小時數加總』與『低於高溫臨界溫度以下的度數加總』和當期批發市場交易總量進行回歸分析。分析結果顯示，11–2 月之前的氣象資料，無論是『低於高溫臨界溫度以下的小時數加總』與『低於高溫臨界溫度以下的度數加總』，皆以 12 月的低溫情況對當期荔枝的產量有最高的相關性，不同品種達到穩定生產之溫度條件不同。以「黑葉」荔枝過去研究為例，10–1 月具有花芽比例分別為 0–3.3%、3.3–46.7%、18.3–72.3% 及 28.3–67%，由此可見 11 月的花芽比例仍低，至 12 月花芽比例才大幅提升，而到 1 月時之花芽比例並沒有再向上提升 (Zhang *et al*. 1997)。上述研究結果顯示，「黑葉」荔枝主要的花芽形成時間應為 12 月，與本試驗結果相呼應。於「玉荷包」荔枝不同月份『低於高溫臨界溫度以下的小時數加總』與批發市場交易總量回歸分析，在 35–10℃的臨界溫度條件下，12 月所有決定係數總平均為 0.2626，相較之下 11 月、1 月、2 月、12–1 月和 11–2 月之決定係數總平均為 0.0705、0.0674、0.0508、0.1766 及 0.1114 (圖 1A)。然而，「玉荷包」荔枝不同月份『低於高

(A)

Critical temperature	Coefficients of determination (R^2) Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
35℃	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34℃	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33℃	0.0378	0.0000	0.0000	0.0000	0.0000	0.0378
32℃	0.3033	0.0000	0.0000	0.3575	0.0000	0.5043
31℃	0.4413	0.3575	0.0000	0.5348	0.3575	0.7176
30℃	0.3583	0.3575	0.3575	0.4641	0.3575	0.6306
29℃	0.3379	0.3196	0.2232	0.1482	0.3185	0.5239
28℃	0.3005	0.3185	0.2134	0.0938	0.3059	0.3829
27℃	0.2268	0.3312	0.0725	0.1157	0.2675	0.3329
26℃	0.2878	0.2949	0.0849	0.1160	0.2306	0.3260
25℃	0.3423	0.4007	0.0354	0.1334	0.2353	0.3822
24℃	0.2652	0.4155	0.0235	0.1411	0.2136	0.4033
23℃	0.2658	0.4121	0.0114	0.0786	0.1946	0.3496
22℃	0.2992	0.4800	0.0052	0.0463	0.2188	0.3304
21℃	0.2696	0.5148	0.0001	0.0106	0.2380	0.2592
20℃	0.1968	0.5224	0.0004	0.0132	0.2862	0.2444
19℃	0.1669	0.5085	0.0234	0.0158	0.3093	0.2349
18℃	0.0759	0.4576	0.0787	0.0268	0.3332	0.2434
17℃	0.0584	0.4352	0.0928	0.0249	0.3428	0.2487
16℃	0.0227	0.4081	0.0884	0.0920	0.3218	0.2847
15℃	0.0112	0.3768	0.0797	0.1369	0.2552	0.2644
14℃	0.0068	0.2402	0.0644	0.1891	0.1584	0.2041
13℃	0.0262	0.2016	0.0298	0.2609	0.0970	0.1677
12℃	0.0849	0.1678	0.0157	0.2240	0.0616	0.1223
11℃	0.0849	0.2074	0.0001	0.1151	0.0248	0.0680
10℃	0.0849	0.2038	0.0173	0.0537	0.0001	0.0113
Average	0.1752	0.3051	0.0584	0.1305	0.1972	0.2798

(B)

Critical temperature	Coefficients of determination (R^2) Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
35℃	0.2579	0.4468	0.0323	0.0741	0.2535	0.2830
34℃	0.2579	0.4468	0.0323	0.0741	0.2535	0.2830
33℃	0.2579	0.4468	0.0323	0.0741	0.2535	0.2829
32℃	0.2575	0.4468	0.0323	0.0741	0.2535	0.2827
31℃	0.2558	0.4468	0.0323	0.0738	0.2535	0.2819
30℃	0.2529	0.4464	0.0323	0.0730	0.2533	0.2801
29℃	0.2476	0.4452	0.0320	0.0721	0.2524	0.2770
28℃	0.2411	0.4445	0.0317	0.0712	0.2514	0.2736
27℃	0.2353	0.4447	0.0310	0.0702	0.2502	0.2705
26℃	0.2276	0.4450	0.0303	0.0686	0.2487	0.2673
25℃	0.2230	0.4457	0.0297	0.0660	0.2477	0.2646
24℃	0.2078	0.4451	0.0293	0.0627	0.2471	0.2582
23℃	0.1963	0.4442	0.0298	0.0598	0.2479	0.2508
22℃	0.1639	0.4428	0.0305	0.0588	0.2484	0.2418
21℃	0.1212	0.4331	0.0325	0.0624	0.2453	0.2315
20℃	0.0869	0.4176	0.0374	0.0717	0.2406	0.2264
19℃	0.0585	0.3951	0.0404	0.0820	0.2279	0.2191
18℃	0.0371	0.3664	0.0389	0.0973	0.2065	0.2078
17℃	0.0300	0.3361	0.0303	0.1217	0.1726	0.1919
16℃	0.0245	0.2978	0.0202	0.1480	0.1287	0.1656
15℃	0.0272	0.2427	0.0118	0.1553	0.0861	0.1293
14℃	0.0410	0.2030	0.0024	0.1493	0.0470	0.0902
13℃	0.0724	0.1854	0.0005	0.1209	0.0174	0.0518
12℃	0.0849	0.1903	0.0123	0.0685	0.0014	0.0171
11℃	0.0849	0.1942	0.0442	0.0320	0.0093	0.0000
10℃	0.0849	0.1440	0.0747	0.0005	0.0416	0.0211
Average	0.1552	0.3709	0.0301	0.0801	0.1900	0.2057

圖 3. 嘉義站 2013–2022 年氣象資料與當年度「竹葉黑」荔枝批發市場交易量之相關性分析。(A)『不同月份低於臨界溫度以下的小時數加總』與『當期批發市場「竹葉黑」荔枝總量』之決定係數 (R^2)；(B)『不同月份低於臨界溫度以下的度數加總』與『當期批發市場「竹葉黑」荔枝總量』之決定係數 (R^2)。相關係數大小以紅色深淺背景表示。

Fig. 3. Correlation analysis of meteorological data at Chiayi and the auction market sold litchi amount of 'Zhu-Ye-Hei' litchi during 2013–2022. (A) The coefficient of determinations (R^2) of accumulated daily hours below the threshold low temperature in different months and auction market sold litchi amount in the current year; (B) The coefficient of determinations (R^2) of accumulated temperature degrees below the threshold low temperature in different months and auction market sold litchi amount in the current year. The numerical value of the coefficients of determination is represented by the shade of red background.

溫臨界溫度以下的度數加總』與批發市場交易總量回歸分析，以 35–10℃的臨界溫度條件下，12 月所有決定係數總平均為 0.2404，相較之下 11 月、1 月、2 月、12–1 月及 11–2 月之決定係數總平均為 0.0103、0.0149、0.0148、0.1355 和 0.0634 (圖 1B)。由此可知，12 月的低溫相較其他月份於「玉荷包」荔枝之產量具有最關鍵的影響，11 月、1 月和 2 月份的低溫對當年度的產量影響明顯較少許多。進一步觀察「黑葉」、「竹葉黑」與「糯米糍」的回歸分析結果可得到與「玉荷包」類似的結果 (圖 2、3、4、5)，結果顯示不同荔枝品種皆以「12 月」的低溫對產量影響最關鍵。

進一步比較各品種 12 月份『不同月份低於高溫臨界溫度以下的小時數加總』與『當期批發市場荔枝總量』之決定係數，可發現「玉荷包」、「黑葉」、「竹葉黑」及「糯米糍」於圖 1A、2A、3A、4A 於不同臨界溫度條件下，決定係數都呈現漸增後漸減的現象，依此方式找到最高的決定係數以作為影響當期荔枝總量最適當的臨界溫度條件。會有這種決定係數隨著臨界溫度漸增後漸減為本分析預期中的現

(A)

Critical temperature	Coefficients of determination (R^2) Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
35℃	0.1482	0.1672	0.2133	0.1831	0.1970	0.1964
34℃	0.1482	0.1672	0.2133	0.1831	0.1970	0.1964
33℃	0.1123	0.1672	0.2133	0.1831	0.1970	0.1884
32℃	0.0803	0.1672	0.2133	0.1831	0.1970	0.1810
31℃	0.0368	0.1441	0.2133	0.1709	0.1839	0.0906
30℃	0.3817	0.0831	0.1991	0.0931	0.1399	0.0055
29℃	0.3912	0.0157	0.1667	0.0422	0.0124	0.2092
28℃	0.3866	0.1670	0.0548	0.0024	0.0386	0.2759
27℃	0.3745	0.4553	0.0017	0.0024	0.2884	0.3608
26℃	0.2595	0.6381	0.1466	0.0102	0.4895	0.4359
25℃	0.2156	0.6957	0.2469	0.0051	0.5672	0.4460
24℃	0.2243	0.7627	0.3209	0.0130	0.6175	0.5106
23℃	0.1449	0.7706	0.3412	0.0170	0.6375	0.5109
22℃	0.2066	0.8215	0.2958	0.0308	0.6756	0.5261
21℃	0.2029	0.8183	0.2900	0.0193	0.6556	0.4692
20℃	0.2543	0.7788	0.3741	0.0191	0.6847	0.4673
19℃	0.3042	0.7864	0.4327	0.0203	0.7344	0.4904
18℃	0.3004	0.7658	0.5406	0.0099	0.7657	0.5155
17℃	0.3097	0.7873	0.6109	0.0162	0.8343	0.5987
16℃	0.2967	0.7681	0.7377	0.0772	0.8739	0.7075
15℃	0.2528	0.7709	0.7429	0.1688	0.8776	0.8012
14℃	0.3520	0.7468	0.7172	0.2462	0.8283	0.8587
13℃	0.4558	0.7015	0.6663	0.3528	0.7644	0.8626
12℃	0.4558	0.5021	0.4840	0.4943	0.5874	0.7969
11℃	0.4558	0.4289	0.2402	0.3808	0.3914	0.6228
10℃	0.0000	0.6617	0.1272	0.2338	0.2576	0.3598
Average	0.2597	0.5284	0.3386	0.1215	0.4882	0.4494

(B)

Critical temperature	Coefficients of determination (R^2) Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
35℃	0.3452	0.8249	0.5391	0.0653	0.7813	0.6458
34℃	0.3495	0.8252	0.5420	0.0665	0.7830	0.6493
33℃	0.3538	0.8255	0.5448	0.0676	0.7846	0.6527
32℃	0.3584	0.8258	0.5475	0.0688	0.7861	0.6557
31℃	0.3628	0.8259	0.5502	0.0699	0.7875	0.6581
30℃	0.3641	0.8261	0.5528	0.0710	0.7890	0.6593
29℃	0.3615	0.8263	0.5553	0.0721	0.7906	0.6595
28℃	0.3541	0.8268	0.5578	0.0736	0.7930	0.6594
27℃	0.3483	0.8268	0.5607	0.0750	0.7951	0.6602
26℃	0.3459	0.8260	0.5639	0.0764	0.7972	0.6620
25℃	0.3478	0.8251	0.5691	0.0789	0.8004	0.6647
24℃	0.3455	0.8243	0.5750	0.0828	0.8052	0.6669
23℃	0.3502	0.8222	0.5801	0.0878	0.8116	0.6695
22℃	0.3536	0.8186	0.5849	0.0926	0.8187	0.6740
21℃	0.3456	0.8134	0.5914	0.0994	0.8261	0.6820
20℃	0.3292	0.8093	0.5952	0.1100	0.8344	0.6971
19℃	0.3267	0.8058	0.5991	0.1241	0.8396	0.7214
18℃	0.3293	0.7950	0.6011	0.1522	0.8402	0.7547
17℃	0.3400	0.7808	0.5864	0.2013	0.8285	0.7882
16℃	0.3593	0.7651	0.5490	0.2649	0.7931	0.8083
15℃	0.3817	0.7165	0.4710	0.3203	0.7087	0.7851
14℃	0.4463	0.6545	0.3427	0.3575	0.5718	0.7029
13℃	0.4558	0.5968	0.1945	0.3797	0.3966	0.5749
12℃	0.4558	0.5341	0.0723	0.3211	0.1972	0.3694
11℃	0.4558	0.5384	0.0102	0.2258	0.0503	0.1505
10℃	0.0000	0.4214	0.0020	0.1370	0.0007	0.0252
Average	0.3526	0.7608	0.4784	0.1439	0.6927	0.6268

圖 4. 南投草屯站 2013–2022 年氣象資料與當年度「糯米糍」荔枝批發市場交易量之相關性分析。(A)『不同月份低於臨界溫度以下的小時數加總』與『當期批發市場「糯米糍」荔枝總量』之決定係數 (R^2)；(B)『不同月份低於臨界溫度以下的度數加總』與『當期批發市場「糯米糍」荔枝總量』之決定係數 (R^2)。相關係數大小以紅色深淺背景表示。

Fig. 4. Correlation analysis of meteorological data at Nantou Caotun and the auction market sold litchi amount of 'No-Mai-Tsz' litchi during 2013–2022. (A) The coefficient of determinations (R^2) of accumulated daily hours below the threshold low temperature in different months and auction market sold litchi amount in the current year; (B) The coefficient of determinations (R^2) of accumulated temperature degrees below the threshold low temperature in different months and auction market sold litchi amount in the current year. The numerical value of the coefficients of determination is represented by the shade of red background.

象。例如高溫臨界溫度設置於 35℃時，35℃以下的小時數加總在荔枝豐產年或減產年的數值都很大，決定係數就相對低。高溫臨界溫度設置於 10℃時，10℃以下的小時數加總在荔枝豐產年或減產年的數值都很小，決定係數也相對低。惟有特定的高溫臨界溫度以下的小時數加總會隨著當期荔枝產量多少呈現明顯的正相關時，決定係數即相對高。因為每個品種對於可抑制新梢生長的溫度條件不同，所以呈現最關鍵臨界溫度也不同。此報告結果之高溫臨界溫度只用於呈現與當期荔枝產量具有最高相關性的臨界溫度條件，至於誘導花芽分化的臨界溫度，則需使用梯度定溫設備才可以進行相關試驗。

為了瞭解『較久的低溫期』或『較冷的低溫』對荔枝產量有比較高的影響，5 個荔枝品種『主產區 12 月低於高溫臨界溫度以下的小時數總合 』與『當期批發市場荔枝總量』之最

(A)

Critical temperature	Coefficients of determination (R^2) Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
35℃	0.0000	0.0000	0.0039	0.0000	0.0039	0.0039
34℃	0.0000	0.0000	0.0039	0.0000	0.0039	0.0039
33℃	0.0000	0.0000	0.0039	0.0000	0.0039	0.0039
32℃	0.0000	0.0000	0.0039	0.0000	0.0039	0.0039
31℃	0.0578	0.0000	0.0039	0.0000	0.0039	0.0653
30℃	0.0761	0.0000	0.0039	0.0000	0.0039	0.0807
29℃	0.1060	0.2903	0.0039	0.1908	0.2064	0.1356
28℃	0.0444	0.2915	0.0298	0.5305	0.3496	0.1042
27℃	0.1030	0.2078	0.0157	0.0711	0.1597	0.1531
26℃	0.1907	0.1448	0.0192	0.0052	0.0945	0.2117
25℃	0.2410	0.0956	0.0923	0.0673	0.0318	0.1683
24℃	0.1908	0.1801	0.0768	0.0401	0.0972	0.1179
23℃	0.1822	0.1917	0.0328	0.0615	0.0889	0.0976
22℃	0.1308	0.0541	0.0867	0.0206	0.0015	0.0395
21℃	0.1081	0.0419	0.0710	0.0359	0.0009	0.0222
20℃	0.1380	0.0635	0.0300	0.0512	0.0134	0.0356
19℃	0.1867	0.0890	0.0177	0.0474	0.0697	0.0726
18℃	0.1846	0.0417	0.0742	0.0135	0.0603	0.0601
17℃	0.1314	0.0517	0.1400	0.0005	0.0993	0.0803
16℃	0.1022	0.1061	0.1163	0.0009	0.1505	0.1152
15℃	0.0757	0.1250	0.1990	0.0003	0.2301	0.1373
14℃	0.0353	0.0894	0.2078	0.0006	0.2069	0.1056
13℃	0.0079	0.0443	0.0897	0.0215	0.0862	0.0724
12℃	0.0128	0.0232	0.0216	0.0565	0.0296	0.0552
11℃	0.0018	0.0039	0.0041	0.0887	0.0048	0.0375
10℃	0.0008	0.0119	0.0044	0.1302	0.0003	0.0220
Average	0.0888	0.0826	0.0522	0.0552	0.0771	0.0771

(B)

Critical temperature	Coefficients of determination (R^2) Nov.	Dec.	Jan.	Feb.	Dec.–Jan.	Nov.–Feb.
35℃	0.1787	0.0798	0.0281	0.0008	0.0725	0.0989
34℃	0.1787	0.0798	0.0281	0.0008	0.0725	0.0989
33℃	0.1787	0.0798	0.0281	0.0008	0.0725	0.0989
32℃	0.1787	0.0798	0.0281	0.0008	0.0725	0.0989
31℃	0.1787	0.0798	0.0281	0.0008	0.0725	0.0988
30℃	0.1788	0.0798	0.0281	0.0008	0.0725	0.0986
29℃	0.1789	0.0798	0.0281	0.0008	0.0725	0.0980
28℃	0.1795	0.0796	0.0281	0.0007	0.0723	0.0966
27℃	0.1803	0.0791	0.0280	0.0007	0.0720	0.0944
26℃	0.1787	0.0785	0.0281	0.0007	0.0719	0.0919
25℃	0.1760	0.0777	0.0284	0.0007	0.0718	0.0897
24℃	0.1686	0.0766	0.0289	0.0009	0.0718	0.0874
23℃	0.1668	0.0742	0.0296	0.0012	0.0712	0.0858
22℃	0.1632	0.0735	0.0314	0.0017	0.0729	0.0850
21℃	0.1555	0.0749	0.0351	0.0023	0.0774	0.0846
20℃	0.1453	0.0748	0.0390	0.0038	0.0814	0.0846
19℃	0.1222	0.0730	0.0419	0.0059	0.0831	0.0819
18℃	0.0898	0.0715	0.0389	0.0091	0.0805	0.0768
17℃	0.0690	0.0737	0.0336	0.0135	0.0774	0.0750
16℃	0.0448	0.0702	0.0247	0.0171	0.0651	0.0657
15℃	0.0297	0.0527	0.0126	0.0241	0.0398	0.0497
14℃	0.0211	0.0348	0.0009	0.0355	0.0120	0.0306
13℃	0.0224	0.0213	0.0035	0.0507	0.0002	0.0162
12℃	0.0190	0.0096	0.0242	0.0583	0.0090	0.0032
11℃	0.0265	0.0070	0.0513	0.0468	0.0312	0.0003
10℃	0.0484	0.0087	0.0943	0.0222	0.0702	0.0130
Average	0.1253	0.0642	0.0307	0.0116	0.0630	0.0732

圖 5.　新竹寶山站 2013–2022 年氣象資料與當年度「桂味」荔枝批發市場交易量之相關性分析。(A)『不同月份低於臨界溫度以下的小時數加總』與『當期批發市場「桂味」荔枝總量』之決定係數 (R^2)；(B)『不同月份低於臨界溫度以下的度數加總』與『當期批發市場「桂味」荔枝總量』之決定係數 (R^2)。相關係數大小以紅色深淺背景表示。

Fig. 5.　Correlation analysis of meteorological data at Hsinchu Baoshan and the auction market sold litchi amount of ‘Gui-Wei’ litchi during 2013–2022. (A) The coefficient of determinations (R^2) of accumulated daily hours below the threshold low temperature in different months and auction market sold litchi amount in the current year; (B) The coefficient of determination (R^2) of accumulated temperature degrees below the threshold low temperature in different months and auction market sold litchi amount in the current year. The numerical value of the coefficients of determination is represented by the shade of red background.

高決定係數 (R^2) 總平均值為 0.6350 (表 1)。而 5 個荔枝品種『主產區 12 月低於高溫臨界溫度以下的度數總合』與『當期批發市場荔枝總量』之最高決定係數 (R^2) 總平均為總平均值為 0.5142 (表 2)。結果顯示，低於高溫臨界溫度以下的『小時數』加總的決定係數平均值較高，表示『較久的低溫期』相較於『較冷的低溫』用於產量預估上較為準確。因荔枝開花比例高的前提為需要一段低溫期停止荔枝新梢生長，即使有相當寒冷的寒流來襲，寒流離開後的高溫則可能造成新梢抽出，減少開花比例 (Menzel & Simpson 1992; Nagao *et al*. 2000)。所以 12 月『較久的低溫期』比『較冷的低溫』對停止荔枝營養生長更為關鍵。

因決定係數 (R^2) 愈高，代表使用氣象資料預估當年度產量的可信度愈高，於本研究中，「黑葉」和「糯米糍」的決定係數高於 8 成，而「玉荷包」的決定系數接近 7 成，使用回歸方程式推估產量的可信度較高。而「竹葉黑」與「桂味」荔枝的決定係數皆為 5 成以下，使用回歸方程

表 1. 5 個荔枝品種『主產區 12 月低於臨界溫度以下的小時數總合』與『當期批發市場荔枝總量』之最高決定係數 (R^2)、臨界溫度及回歸方程式。

Table 1. The highest coefficient of determination (R^2), threshold temperature and regression equation of accumulated daily hours below the threshold temperature in December and auction market sold litchi amount in the current year of five litchi varieties.

Variety	Weather station	The threshold temperature of highest coefficient of determination (℃)	Coefficient of determination (R^2)	Regression equation
'Yu-Her-Bao'	Kaohsiung Xipu	24	0.6938	y = 12.267x – 5529.6
'Hei-Yeh'	Taichung Zhongzhulin	13	0.8578	y = 15.083x + 301.69
'Zhu-Ye-Hei'	Chiayi	20	0.5224	y = 1.7721x – 434.88
'No-Mai-Tsz'	Taichung Caotun	22	0.8215	y = 4.3849x – 2258.5
'Gui-Wei'	Hsinchu Baoshan	29	0.2794	y = 360.77x – 268030
Average			0.6350	

表 2. 5 個荔枝品種『主產區 12 月低於臨界溫度以下的度數總合』與『當期批發市場荔枝總量』之最高決定係數 (R^2)、臨界溫度及回歸方程式。

Table 2. The highest coefficient of determination (R^2), threshold temperature and regression equation of accumulated temperature degrees below the threshold temperature in December and auction market sold litchi amount in the current year of five litchi varieties.

Variety	Weather station	The threshold temperature of highest coefficient of determination (℃)	Coefficient of determination (R^2)	Regression equation
'Yu-Her-Bao'	Kaohsiung Xipu	30	0.3537	y = 0.6152x – 2764.6
'Hei-Yeh'	Taichung Zhongzhulin	15	0.8638	y = 3.048x + 281.09
'Zhu-Ye-Hei'	Chiayi	35	0.4468	y = 0.1464x – 1358.7
'No-Mai-Tsz'	Taichung Caotun	32	0.8268	y = 0.2454x – 1334.8
'Gui-Wei'	Hsinchu Xiangshan	35	0.0798	y = 0.0775x – 686.99
Average			0.5142	

式推估產量的可信度較低。過去資料顯示，「黑葉」荔枝占全台荔枝品種比例約 67.6%，「玉荷包」荔枝占 25.5%，「糯米糍」占 2%，其它品種共占 4.8% (Zhang & Teng 2011)。因種植面積愈大，產區愈集中，使用氣象資料推估產量的可信度有較高的現象，故未來若要以氣象資料推估當年度產量，以「黑葉」、「糯米糍」及「玉荷包」的回歸方程式可信度較高。而「竹葉黑」、「桂味」荔枝的種植面積較少且產地較為分散。於本試驗分析結果顯示，11–2 月的氣象資料與當期批發市場交易總量的相關性較低，高溫臨界溫度之可信度低，較不適用於產量預估。

因「黑葉」、「玉荷包」和「糯米糍」的種植面積較大且產區較集中，統計分析可信度較高，未來可使用回歸方程式進行當期荔枝的產量預估 (表 1、圖 6)。以「黑葉」荔枝為例，先取得主產區 12 月低於 13℃臨界溫度以下的小時數總合作為 x 值，代入 y = 15.083x + 301.69 的回歸方程式，即可預估當年的「黑葉」批發市場交易總量 y 值。再和其他年份的交易總量進行比較，即可提前預估當期荔枝產量多寡。

本文重申於本研究所推估出的高溫臨界溫度 (表 1、2)，並不代表各品種誘導花芽分化的臨界溫度，而是與產量最相關的臨界溫度，此臨界溫度包含足夠的高低溫資訊，可用於推估當期荔枝產量。整理 5 個荔枝主產區於 2013–2022 年的每月平均溫度 (圖 7)，進一步觀察 11 月至 2 月的氣溫中，以 1 月的氣溫最

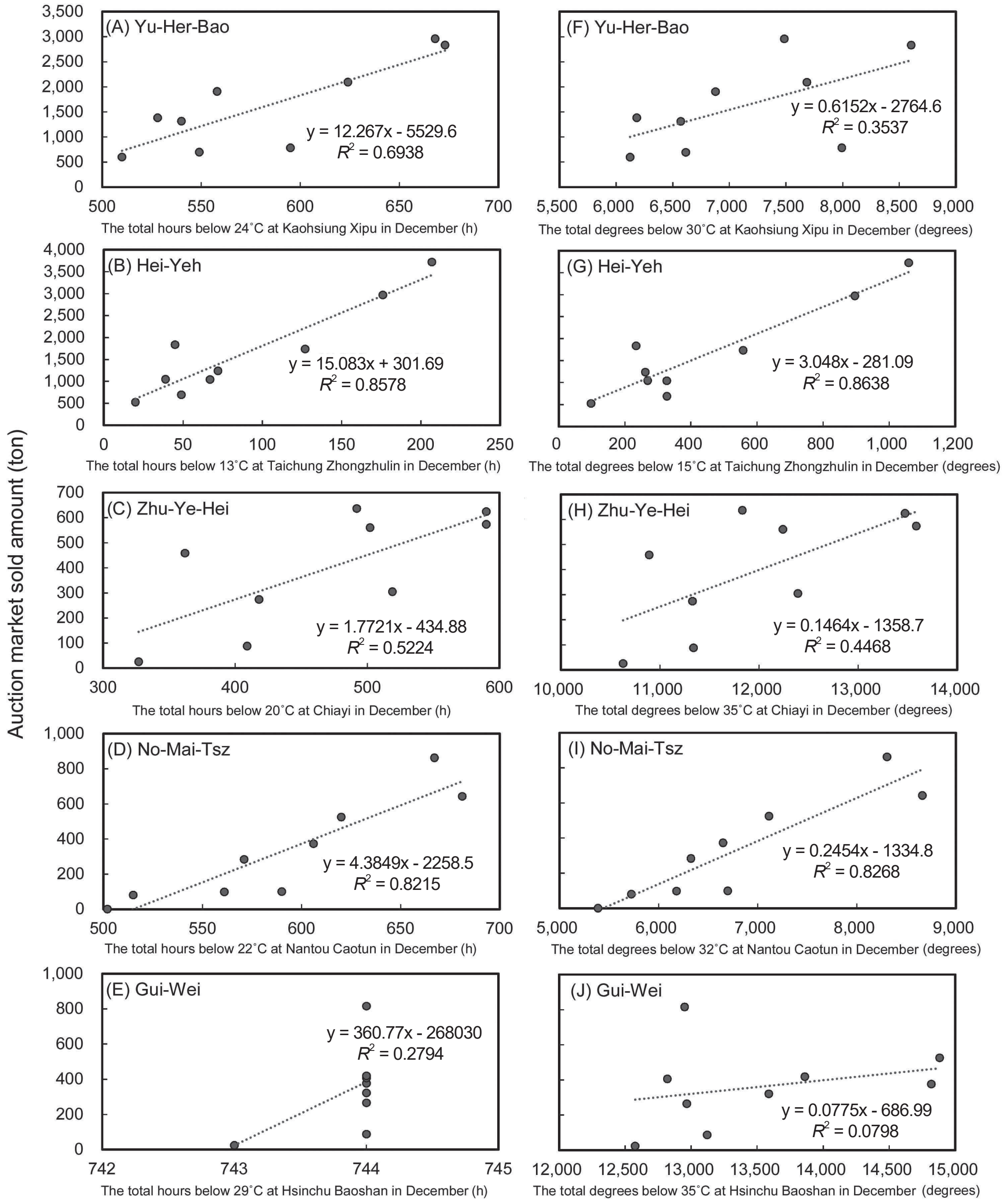

圖 6.　5 個荔枝品種『主產區 12 月低於臨界溫度以下的小時數總合或度數總合』與『當期批發市場荔枝總量』之最高決定係數 (R^2)、臨界溫度及回歸方程式。

Fig. 6.　The highest coefficient of determination (R^2), threshold temperature and regression equation of accumulated daily hours and temperature degrees below the threshold temperature in December and auction market sold litchi amount in the current year of five litchi varieties.

Weather station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Hsinchu Baoshan	15.2	15.3	17.6	20.7	24.3	26.8	27.6	27.0	26.0	23.3	20.8	16.8
Nantou Caotun	17.4	18.1	20.7	23.6	26.6	28.3	29.0	28.5	28.3	26.0	23.2	18.9
Taichung Zhongzhulin	15.9	16.6	19.2	21.8	24.6	26.1	26.6	26.0	25.8	23.7	21.2	17.1
Chiayi	17.4	18.2	20.9	23.9	27.1	29.0	29.3	28.6	28.2	25.7	22.9	18.9
Kaohsiung Xipu	18.9	19.7	22.4	25.0	27.3	28.3	28.4	27.6	27.9	26.3	24.1	20.2

圖 7. 5 個荔枝主產區於 2013–2022 年的每月平均溫度。相關係數大小以紅色深淺背景表示。

Fig. 7. Monthly average temperature of 5 main litchi producing areas during 2013–2022. The numerical value of the coefficients of determination is represented by the shade of red background.

低，2 月氣溫次之，12 月的氣溫再次之，而 11 月的氣溫最高。本分析結果發現 12 月的氣溫對荔枝產量的影響最大，而不是氣溫更低的 1、2 月。對比台灣荔枝的生育狀態，通常於 12 月處於停梢狀態、1 月為停梢至萌動狀態、2 月為花芽抽出的時間。由以上結果推論，12 月的停梢狀態穩定度受到氣象影響甚劇。若 12 月沒有一個穩定的低溫期使荔枝處於休眠狀態，即使 1 月及 2 月有寒冷的低溫，仍會有產量不穩定的影響。

Intergovernmental Panel on Climate Change (IPCC) (n.d.) 提出的『全球增溫攝氏 1.5℃特別報告』，揭示全球暖化將會造成的重大的災情。以荔枝為例，若將荔枝低溫處理後，再以 20℃以上溫度處理，結果顯示 20℃的時間愈長，愈不利花芽分化 (Menzel & Simpson 1995)。荔枝於低溫持續時間 6–8 wk 的成花比例高，短於 4 wk 的不成花或帶葉花序比例高 (Menzel & Timpson 1989)。由此可知，低溫期愈長對開花穩定性提升有幫助，若冬季遇到較高的溫度亦會影響開花穩定性。據農糧署農業統計年報顯示，台灣荔枝種植面積 2000–2010 年介於 12,000 ha 左右，這些年間面積波動不大。但從 2010 年荔枝種植面積由 11,717 ha 降至 2020 年的 9,726 ha，減少近 2,000 ha (https://agr.afa.gov.tw/afa/afa_frame.jsp)。分析荔枝主產區台中和高雄 1995–2021 年的 12 月均溫，兩個地區的 12 月均溫皆呈現上升趨勢 (圖 8)，若比較 1995–2014 年與 2015–2021 年平均資料，可發現台中和高雄 12 月均溫於近 6 年已較前 20 年提高 1.21℃與 1.45℃ (表 3)。比對批發市場交易總量資料可知，對荔枝生產已開始造成影響 (圖 9)。

結論

雖然荔枝採收後，並不是全數送往批發市場交易，另有行口、宅配、傳統市場或外銷等交易方式。但因「黑葉」、「玉荷包」及「糯米糍」荔枝的栽培面積較大且產區集中，推估每年有固定比例果農送往批發市場，由批發市場總交易量模擬當年產量與氣象資料進行分析有其應用合理性與實用意義。本研究分析結果顯示，12 月『較長的低溫期』比『較寒冷的溫度』對產量的影響更關鍵，可使用 12 月氣象資料推估當期「玉荷包」、「黑葉」及「糯米糍」的荔枝產量，來提供農政單位提早進行產銷因應之參考依據，或內外銷業者亦可提早進行交易通路規劃。至於荔枝栽培者，則應確實於 11 月進行適當的停止晚梢動作，使荔枝於 12 月穩定處於停梢狀態，待 1 月份植體感受低溫時，較可提高開花比例。根據中央氣象局測站觀測資料，台灣年平均氣溫在過去 110 年 (1911–2020 年) 上升約 1.6℃，且近 30 年增溫有加速的趨勢。台灣氣候變遷科學團隊推估未來台灣各地氣溫將持續上升，全球暖化最劣情境 [shared socioeconomic pathway (SSP) 5–8.5] 下，21 世紀中、末之年平均氣溫可能上升超過 1.8℃、3.4℃；理想減緩情境 (SSP 1–2.6) 下，可能增加 1.3℃、1.4℃ (Taiwan Climate Change Projection Information and Adaptation Knowledge Platform 2021)。荔枝產業應密切注意暖冬是否持續，若氣候暖化趨於常態，將會對荔枝生產

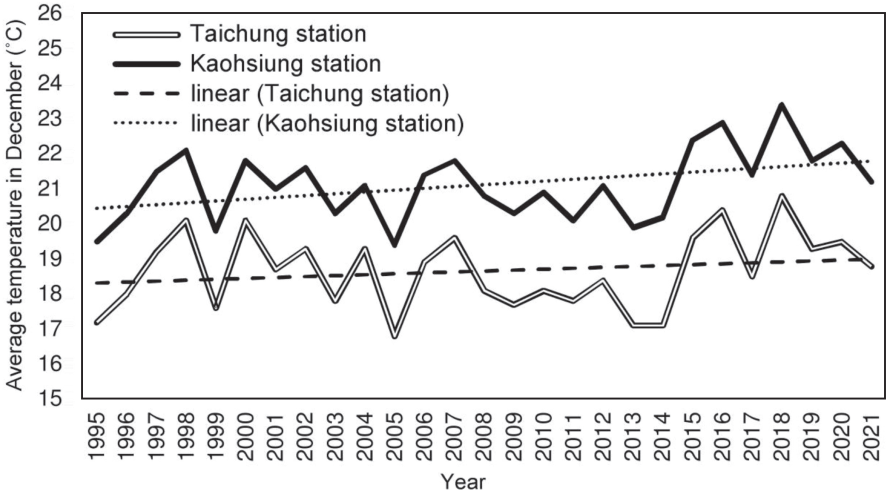

圖 8. 高雄市與台中市氣象站 1995–2021 年 12 月平均溫度。

Fig. 8. The average temperatureat measured at Kaohsiung and Taichung weather stations in December during 1995–2021.

表 3. 高雄市與台中市氣象站 1995–2021 年 12 月平均溫度比較。

Table 3. The average temperature difference measured in December at Kaohsiung and Taichung weather stations during 1995–2021.

Weather station	Average temperature in December (℃) 1995–2014	2015–2021	Average temperature difference between 1995–2014 and 2015–2021 (℃)
Taichung	18.35	19.56	1.21
Kaohsiung	20.75	22.20	1.45
Average temperature difference between Taichung and Kaohsiung (℃)	2.40	2.64	

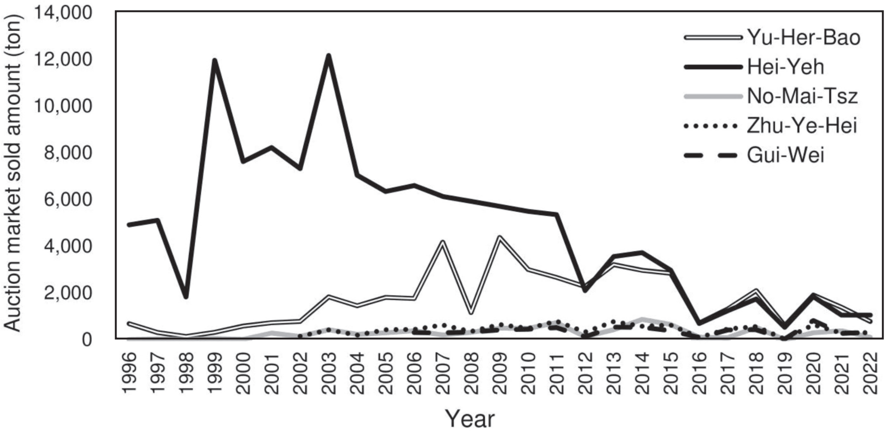

圖 9. 5 個荔枝品種 1996–2022 年全台批發市場交易總量。

Fig. 9. The total auction market sold litchi amount for five litchi varieties during 1996–2022 in Taiwan.

造成嚴重影響。長期下來則會造成荔枝栽培區域向北移動等現象。農業試驗所鳳山熱帶園藝試驗分所早年有鑑於全球暖化的發生，即提早著手極早熟荔枝品種的選育，並於 2011 年推出荔枝「台農 6 號 (黰荔)」，因其刺激花芽分化所需的低溫需求較「玉荷包」與「黑葉」荔枝少，於暖冬年亦可穩定開花，屬極早熟品種，未來若暖冬持續發生，此品種可作為品種更新的選擇 (Teng & Chen 2011)。未來鳳山熱帶園藝試驗分所將持續進行極早熟與優質荔枝品種選育，以及耐候穩產相關栽培技術開發，以減少氣候暖化對荔枝產業之衝擊。

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Feasibility Study on Using Meteorological Data to Forecast Litchi Yield

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Abstract

Fang, H. H., K. D. Chiou, C. C. Hsu, and W. L. Lee. 2022. Feasibility study on using meteorological data to forecast litchi yield. J. Taiwan Agric. Res. 71(4):343–357.

The annual yield of litchi is greatly affected by the temperature in winter. Low temperature can stimulate the stable differentiation of flower buds. However, the production will be reduced due to unstable differentiation of flower buds and decreased flowering ratio in mild winter. This study considers different litchi varieties, which are distributed in the main producing areas in Taiwan. The meteorological data was collected from November to February of the following year in the past 9 years close to the weather station in the main producing area. The sum of the daily hours ranging from 10℃ to 35℃ and the total sale volume of litchi in the auction market in the current season were evaluated by regression analyses. The results indicated that the temperature in December had the highest correlation with the auction market sold litchi amount in the current year. A longer low temperature period was more critical to yield than colder temperature. The accumulated daily differential hours below 24℃, 13℃ and 22℃, respectively, and the previous sold amounts of 'Yu-Her-Bao', 'Hei-Yeh' and 'No-Mai-Tsz' litchi in the recent years are processed for correlation analysis. The coefficients of determination (R^2) reached 0.6938, 0.8578, and 0.8215, respectively. In the future production estimation, depending on the variety, the number of hours below the threshold temperature in December could be applied to the equation to predict the litchi yield in the current year. This innovative method can be used as a reference for the production and sales adjustment of agricultural sector or for litchi operators to plan domestic and foreign sales orders in advance.

Key words: Litchi, Yield, Warming, Meteorological data.

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台灣農業研究

(原《中華農業研究》期刊)

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「台灣農業研究」稿約

一、 本刊為行政院農業委員會農業試驗所發行之學術性期刊 (季刊)，刊登國內、外農業試驗研究相關之研究稿件：

專題論述：由本所期刊編審會或總編輯邀請專家撰寫。

研究報告：關於農業科學未曾發表之研究報告，按題目、作者、摘要、前言、材料與方法、結果、討論、結論 (一般略去，或併入討論)、誌謝 (可略去)、引用文獻等依序撰寫，表與圖附於其後，全文以不超過10印刷頁為原則。其中，'結果' 與 '討論' 如有必要，可合併成'結果與討論'。

研究簡報：關於農業科學未曾發表之簡短原始研究報告，不須分章節撰寫 (亦可參照研究報告次序)，但須附中英文摘要，全文以不超過4印刷頁為原則。

二、 稿件應以中文或英文撰寫，以文書軟體MS WORD®格式儲存成檔案 (檔案類型以Word 97–2003或以上版本文件為佳)。文稿以A4大小 (長29.6公分，寬21公分) 兩倍行高 (double space) 繕打，加行號，12號字體，左邊對齊，版面應預留上下3公分，左右2公分之空間，並自第二頁起在右下角以阿拉伯數字註明頁數。撰寫時，中文以細明體、英文以Times New Roman字體打字；英文字距及句距皆一字節。

三、 投稿者在本刊線上投審系統首頁 (http://www.ipress.tw/J0042) 點選'投稿'，確認及點選稿件已依照稿約撰寫無誤後，下一步即填寫稿件資料，務請填寫封面信函，再依序填寫作者資料、上傳檔案及確認提交。

四、 稿件格式：

題　目：宜簡短，能充分反應文旨，並附簡題 (Running title) (中文12字；英文6字以內為原則)。英文題目除介系詞、連接詞等字外，每字第一字母應大寫。報告如有機關所屬編號，請列於誌謝。

作　者：作者姓名置中，作者二人或二人以上時，以中文一全形空格間隔之；英文姓名則名在前姓氏在後，作者二人或二人以上時，以 " , " 相隔，最後一人前加 "and" 字樣，其表示方法如Chen-Seng Huang, Chen-Chang Chen, and Chyr-Guan Chen。每一作者須附小註，以說明所屬機關單位與職稱，通訊作者附予星號" * "，並須附電子郵件信箱。題目與作者同置第一頁。

摘　要：不分段落、宜簡潔明確。摘要之前應加作者、年代、題目、期刊、及卷期，摘要之後應附關鍵詞 (Key words)，關鍵詞不超過五個，每個英文關鍵詞第一字母應大寫。摘要以不超過五百字為原則。以中 (英) 文發表者須附英 (中) 文摘要，置於本文之後，且內容須與中 (英) 文摘要相符，並附通訊作者、作者之小註。

本　文：依序為前言 (INTRODUCTION)、材料與方法 (MATERIALS AND METHODS)、結果 (RESULTS)、討論 (DISCUSSION)、結論 (CONCLUSIONS)、誌謝 (ACKNOWLEDGMENTS)、引用文獻 (REFERENCES)。除學名、專有名詞、化學式、數學公式、數字、度量衡單位及縮寫外，文句中不得中外文並用，需使用英 (外) 文以助明瞭時，須將英 (外) 文括號置於中文之後。材料與方法、結果兩部分如有必要須分段 (節)，每一段內並可再分小段，以助明瞭文稿內容。各段題目 (heading) 單行置於該段之前，小段題目 (subheading) 直接置於小段之首。如因結果繁複不易聯接討論，可合併成'結果與討論 (RESULTS AND DISCUSSION)'。如有附錄，請置於引用文獻之後。

表　　格：

1. 每一表格應分別繕製，須以MS WORD®中 “表格” 工具製作，上方須有標題，以句點結尾，並按文中出現順序加上表**1. (Table 1.)**，表**2. (Table 2.)** 等冠號。
2. 中文稿之表格標題應中英文並列，冠號與表幅齊頭，表內項目及內容以英文書寫。英文標題及各欄英文細目，除第一字之第一字母大寫外，餘均小寫。單位使用SI units (如 g L^{-1}、Mg ha^{-1}、m s^{-1})，一律單數、英文字母。
3. 表格應加分析、簡化與歸納後始可列表。每一表格應在文中標示清楚，以便對照，且每一表格應單頁製作。
4. 表中內容如需說明，均須附加小註，以z, y, x, ...等縮小小寫字母置於右上角，並於表下依次敘述。表格僅列橫線。星號 “* (5%顯著性水準)”、“** (1%顯著性水準)” 保留統計顯著性使用。
5. 性質類同之圖與表，務請精簡與合併。

圖　　片：

1. 手繪圖版以黑色墨水於白色紙上分別繪製，掃描後存成JPG電子檔 (或JPEG電子檔) 上傳。如以電腦繪圖，力求清晰，亦存成JPG檔 (或JPEG檔) 上傳，或直接貼於本文之後。請勿使用MS Office內建軟體繪圖，建議使用專業繪圖軟體 (如Sigma Plot) 繪製。
2. 圖中所有標示應以英文書寫 (Arial字型) 或註明於標題之後小標一律以(A), (B), (C), ...編號，編號以置入圖框為原則，分類學則可以1, 2, 3, ...標示。
3. 照片以光面紙為原則，清晰度以縮小50%可判讀為宜。多幅照片儘量製成併版；如有特別指明，應加圈或箭頭表明。顯微照相，應加比例尺大小；照片大小以不超過版面 (25 cm × 18 cm) 為宜，掃描後存成JPG檔 (或JPEG檔) 上傳，解析度300 dpi或以上，並直接貼於本文之後。
4. 圖版及照片應有標題，並按文中出現的順序加上 **(圖1) (Fig. 1)**、**(圖2) (Fig. 2)** 等冠號，在文中須標示清楚，以便對照。中文稿標題應中英文併列，英文稿標題以英文書寫即可，力求明確。
5. 除併圖外，每一圖片應單頁製作。
6. 圖版及照片未達印製之解析度要求，文稿將不予刊登。

誌　　謝：不分段落，包括人物、經費來源、報告之機關賦予編號等。誌謝可略去。

引用文獻：

1. 列舉確實曾引用之文獻。文獻以登載於學術性期刊、書籍、研討會之文章及學位論文為限 (不含推廣報告)，如引用網路學術性報告，須加註瀏覽、下載日期及網址路徑。
2. 文中涉及引用文獻時，根據該文獻的作者與年代加以括號：如 (Sung 1991)、(Lo 1991, 1992)、(Chen & Ho 1983)、(Sung 1991; Hsu *et al*. 1992)，以年代先後為序置於引用文處。
3. 文獻一律以英文撰寫，以姓名字母為序。作者相同時以年代先後為序。
4. 文獻之書寫方法以期刊為例，依序為作者、年代、題目、期刊、卷數、頁數。在每卷每期之頁碼都從數字 1開始的期刊，才必須加上期數。
5. 期刊名須依該期刊公告之縮寫撰寫；如無者，請參照Biosciences Information Service (1992) 出版之 “Serial Sources for the BIOSIS Previews Database” 或依該學術領域之慣例撰寫。

6. 文獻書寫範例如下：

(1) 原中文報告引用文獻出自學術性期刊

Hsu, S. H., T. Y. Chung, T. C. Kuo, and S. F. Wang. 1992. Studies on the micro-climate of greenhouse. I. Light environment of greenhouse. J. Agric. China 157:34–43. (in Chinese with English abstract)

(2) 原中文報告引用文獻出自著作性書籍

Sung, J. M. 1991. Nitrogen Metabolism of Rice. Chinese Agronomy Press. Taipei. 100 pp. (in Chinese)

(3) 原中文報告引用文獻出自編輯性書籍

Yang, C. M. and C. Y. Lin. 2003. Studies on rice precision farming system. p.1–12. *in*: Rice Precision Farming System. (Yang, C. M. and C. Y. Lin, eds.) Taiwan Agric. Res. Inst. Pub. No. 105. Taichung, Taiwan. 252 pp. (in Chinese with English abstract)

(4) 原中文報告引用文獻出自研討會專刊

Chang, C. A. 2001. Application and extension of virus-free seedling for the control of virus diseases of passion fruit in Taiwan. p.31–38. *in*: Proceeding of Symposium on Application of Healthy Plant for Control of Plant Diseases. November 24, 2001. Taichung, Taiwan.Taiwan Phytopathol. Soc. Publ., Taichung. (in Chinese with English abstract)

(5) 原報告引用文獻出自特定網頁資料

Lehtomäki, A. 2006. Biogas production from energy crops and crop residues. Jyväskylä Stud. Biol. Environ. Sci. 163. Univ. of Jyväskylä, Jyväskylä, Finland. https://jyx.jyu.fi/dspace/bitstream/handle/123456789/13152/9513925595.pdf (visit on 12/16/2014)

五、 單位、縮寫格式、括號及統計分析

1.凡文中出現之數值，除非另有特別之意義，一律用阿拉伯數字書寫。數字在句首之英文稿，改以文字表示。單位則用國際公認標準符號 (SI units) 代替全文，各常用之縮寫單位參照說明如下：

(1) 長度：公里 (km)、公尺 (= 米) (m)、公分 (= 厘米) (cm)、公釐 (= 毫米) (mm)、微米 (μm)。

(2) 重量 (W)：公噸 (Mg)、公斤 (kg)、公克 (g)、毫克 (mg)、微克 (μg)。

(3) 容積 (V)：公升 (L)、公撮 (= 毫升) (mL)、微升 (μL)。

(4) 面積：公頃 (ha)、平方公尺 (m^2)、平方公分 (cm^2)。

(5) 溫度：攝氏 (℃)、絕對溫度 (K，但須加以說明)。

(6) 時間：日 (天) (d)、時 (h)、分 (min)、秒 (s)。

(7) 濃度：莫耳 (M)、千分之一莫耳 (mM)、當量 (N)、千分之一當量 (mN)。

(8) 重力加速度：*g*。

(9) 分子量：kDa。

(10) 肥料三要素：如以肥料種類$N\text{-}P_2O_5\text{-}K_2O$，如以元素N-P-K。

2.其他之縮寫：平均 (*avg*.)、大約 (*ca*.)、直徑 (diam.)。

3.括號：括號字型全以半形 ( )，括號前後各空一格。

4.統計分析：達顯著性水準以*、**或處理間顯著差異區分，以a、b、c、…表示者均應加註顯著機率值*P* (例如$P < 0.01$)；各統計量請採慣用符號，例如相關係數 (*r*) 、決定係數 (R^2)、變異係數 (cv)、標準差 (sd)、平均值標準差 (se) 等。

5.其他問題：

(1) 單位與其前面數值之間應空一格，如220 g。

(2) 數學運算符號與其前後數值之間應各空一格，如$P = 0.014$、23.6 ± 3.0、15×2。

(3) 在 ±、to的前後數值若含有單位，在單位相同時保留後單位即可，以減少贅詞，如23.6 ± 3.0%、20 to 30℃。在×的前後數值則保留，如15 cm × 2 cm。

(4) 數值起迄符號用– (半型破折號；EN Dash)，勿用 ~ 或 -，且與前後兩數值之間無須留空格，如3–6、2005–2007年、7月20–25日。

(5) 年代一律用西元。

(6) 濃度與容量單位使用mg L^{-1} (勿用ppm)。

(7) 轉速單位使用× *g* (勿用rpm)。

六、 其他注意事項

1. 本刊採網路線上投審，來稿請至本刊線上投審系統網址 (http://www.ipress.tw/J0042) 進行投稿作業，投稿前務請詳閱稿約及投稿須知，並可參閱最新一期報告。
2. 生物學名以斜體字表示，屬名第一字母大寫。學名於摘要、本文、每一圖表中第一次出現時，須寫全名，如*Citrus sinensis*；第二次出現時，屬名保留第一字母後加句點 “.”，種名全寫，如*C. sinensis*。生物學名於本文中首次出現時應加註命名者，如*Oryza sativa* L.。
3. 中文稿件中，外文名詞應儘量翻譯成中文，若是不常見名詞應於文中第一次出現時以括號標出原文。摘要及本文中，英文縮寫於第一次出現時，須附全名。圖版及照片如有英文縮寫，應於標題中附全名，表格內之英文縮寫，須於小註附全名。
4. 農作物品種名須加上單引號，中文用「 」(如水稻「台稉9號」、木瓜「台農2號」)，英文用‘’ (如rice ‘TK9’, papaya ‘TNG2’)。

七、 投稿方式

1. 稿件內容務須依照上列規定格式書寫及線上投稿，本期刊編審會保有修改與退稿之權利。文稿經本期刊接受後，由作者負責前二校。除筆誤與錯字外，作者在校稿時，不得擅自更改內容與數據。
2. 投稿前請詳閱稿約及參見最一期刊登報告，投審稿件程序請上網參閱本期刊網址：http://www.ipress.tw/J0042。

八、 投稿本期刊之稿件，不得投稿其他刊物。稿件經本期刊接受後，刊登權屬發行單位農業試驗所所有，非經本所書面同意，不得轉載或移轉他處發表。本期刊具專屬版權，恕不受理一稿兩投之文章 (已刊載或投寄國內外有版權刊物之文章，請勿再投稿本刊)。若有上述情事除依相關法律處理責由作者自負外，本刊將列入紀錄永不受理其投稿。

九、 本刊以黑白印製為原則，彩圖經編審會同意得以彩色編印。本期刊彩圖編印收費標準調整如下表，由作者自行向廠商支付，未付清前稿件將不予刊登。

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4	11,000	$5,000 \times 1 + 2,000 \times 3$
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6 張以上	15,000 起	$5,000 \times 1 + 2,000 \times (n - 1)$

十、 其他未盡事宜本期刊得隨時修正或補充。

Instructions to Authors

Journal of Taiwan Agricultural Research (revised on 2 December 2019)

General Information

The *Journal of Taiwan Agricultural Research* (JTAR) is published four issues annually by the Taiwan Agricultural Research Institute (TARI). Researchers and scientists willing to make the contribution in the fields of agricultural development by publishing their full papers of original research, reviews, or short communications in the Journal are highly welcome and appreciated. Research staff affiliated with TARI is not a requirement for publishing in JTAR. All manuscripts should be submitted online at the Journal's website, http://www.ipress.tw/J0042. Follow its instructions. Submissions to JTAR must not simultaneously submit to any other scientific or technical journal.

Scope

After critical review and approval by the editorial board, JTAR publishes articles in plant science; biotechnology; agricultural chemistry; plant protection; agricultural engineering; agricultural economics and extension; industrial strategic management; biostatistics; and bioinformatics. Articles reporting experimentation or research findings in these fields will be peer-reviewed as research articles. Short articles (no more than 4 printed pages) concerned with experimental techniques, results, or unique phenomena will be peer-reviewed as short communications. Review articles will be under invitation by the editorial board of JTAR.

Style

See the latest issue of JTAR for style and layout. General rules are as follows:

- All abbreviations should be defined at the first mention and in tables and figures, and be used throughout the entire article.
- The Latin names of organisms (e.g., plants, pathogens, insects and pests) must always list when appeared at first appearance (in Abstract or text). Give the complete binomial and authorities.
- At first listing both the common and chemical names of pesticides must be given.
- SI units must be used in the manuscript.
- Use the 24-h time system (e.g., 0200 and 1400) and abbreviate dates such as 3 October 2015 or 10/03/2015.
- Except when used with units, spell out numbers one through nine. Put commas for the decimal separator (e.g., 1,356,078 and 6,078) and place a zero before the decimal point (e.g., 0.6078 and 0.078).

Preparation of Manuscript Files

All submitted manuscript files should write in Chinese or English and save it in Microsoft Word 97–2003 or later versions (.doc files or .docx files). Other word processing software is not accepted. High-resolution figure files may be included in manuscript and submitted separately in forms of .jpg files

or .doc files or .docx files, one figure per file. Do not use word processing features such as automated bulleting and numbering, head and subhead formatting, or internal linking. Text should be typed in A4 size (29.6 cm long, 21 cm wide) in double-spaced and be numbered and aligned to the left side, while tables use single-spaced. Only one font and size (font no. 12) is used. Provide the document with an upper and lower margin of 3 cm and a left and right margin of 2 cm. Starting from the second page, indicate the page number on the lower right corner. When typing the manuscript, use the font of MingLiu (細明體) for Chinese and Times New Roman for English. Leave a single space between each English word and sentence. The author submitting the manuscript should click on "Authors" on the front page of Journal's Online Submission and Review System. Under "Author" page, click "Submit a new manuscript". Confirm submission checklist and then complete the information related to the manuscript including a cover letter.

Follow the sequence and instructions to fill out and upload the information. JTAR adopts a double-blind review for all submitted manuscripts. Reviewers will be able to download the submitted files that authors upload to the system. There are three main types of articles published by JTAR, i.e., "Reviews", "Research Articles", and "Short Communications".

Reviews. A review article is invited by editor-in-chief of JTAR and will be reviewed and revised to assure an appropriate style and content.

Research Articles. Write a research article according to the mentioned scope in the following sequence: title, author(s), abstract, and text. Attach tables, figure captions, and figures at the end of text. In general, each manuscript should not exceed 10 printed pages.

Short Communications. An article that has a size less than 4 printed pages concerned with experimental techniques, results, or unique phenomena may be published as a short communication when accepted.

Title. A title highlights the subject and purpose of the article briefly but clearly. Use common names of crops, avoid abbreviations, and limit words where possible. Except prepositions and connectives, capitalize each word in the English title. Write down the suggested running title, with no more than twelve Chinese characters or six English words, in the next sentence.

Author. List names of all authors below the title and place an asterisk after the corresponding author. The next sentence lists professional titles, institutions and complete addresses of all authors. Provide e-mail address of the corresponding author. Place title and author(s) on the same page.

Abstract. Each article has a single self-contained paragraph, containing the rationale, objectives, methods, results, and their meaning or scope of application specifically. Identify the important details to interpret the results but try not to exceed five hundred words. Do not cite references and avoid equations. In the next sentence, include no more than five key words and capitalize the first letter of each word. If the manuscript written in Chinese (English), place English (Chinese) abstract after the main text of the manuscript.

Text. The text includes the following sections in sequence: INTRODUCTION, MATERIALS AND METHODS, RESULTS, DISCUSSION, CONCLUSIONS (optional), ACKNOWLEDGMENTS (may be omitted), and REFERENCES. If required, combine the results and discussion section into "RESULTS AND DISCUSSION", and incorporate the conclusions into the discussion. If there is an appendix, place

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  Sung, J. M. 1991. Nitrogen Metabolism of Rice. Chinese Agronomy Press. Taipei. 100 pp. (in Chinese)
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- Reference from a proceedings written in Chinese:
  Chang, C. A. 2001. Application and extension of virus-free seedling for the control of virus diseases of passion fruit in Taiwan. p.31–38. *in*: Proceeding of Symposium on Application of Healthy Plant for Control of Plant Diseases. Taichung, Taiwan. November 24, 2001. Taiwan Phytopathol. Soc. Publ., Taichung. (in Chinese with English abstract)
- Reference from a website:
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Units, Abbreviations, and Statistical Analysis

Use the SI system (Systéme International de Unités) in JTAR. Some commonly used abbreviated units:

- Length: kilometers (km), meter (m), centimeter (cm), millimeter (mm), micrometer (μm)
- Weight (W): ton (Mg), kilogram (kg), gram (g), milligram (mg), microgram (μg)
- Volume (V): litre (L), millilitre (mL), microlitre (μL)
- Surface: hectare (ha), square meter (m^2)
- Temperature: Celsius (℃), absolute temperature (K, but must be indicated)
- Time: day (d), hour (h), minute (min), second (s)
- Concentration: mole (M), millimole (mM), normal (N), millinormal (mN)
- Gravitational acceleration: *g*
- Molecular weight: kDa
- Three macronutrients in fertilizers: element─N-P-K ; equaivalent quantity─N-P_2O_5-K_2O

  Other abbreviations:
- Average: *avg*.
- Approximate: *ca*.
- Diameter: diam.
- Concentration: e.g. mg L^{-1}.
- Frequency of a rotation: × *g*.

Statistical Analysis

Manuscripts should contain enough details of experimental design so that the results can be judged for validity and repeatability. The symbols * and ** are used to show differences in statistical significance. Add *P* value (e.g. $P < 0.01$) when a, b, c, ... are used to classify statistical significance. Examples of commonly used symbols: *r* for correlation coefficient, R^2 for coefficient of determination, cv for coefficient of variation, sd for standard deviation, and se for standard error.

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